AIDE-MÉMOIRE

TO

THE MILITARY SCIENCES.

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PALÆONTOLOGY - - - - - ZIG-ZAG.

WITH NUMEROUS PLATES AND WOOD-CUTS.

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LIST OF PLATES

TO

THE THIRD VOLUME.

NUMEROUS WOOD-CUTS.

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OF

THE THIRD VOLUME.

AIDE-MÉMOIRE.

P.

PALÆONTOLOGY.*—The doctrine of ancient organic bodies, or the natural history of the earth at successive epochs of its former existence.

In the article 'Geology' it has been shown that the study of the mineral crust of the earth brings before an observer subjects of the greatest interest in the proofs which it unfolds of the existence of successive races of organic beings, and of the important share which the relics of such organisms had in the formation of that crust.

The great result of such inquiries is—that at successive epochs new assemblages of vegetables and animals appear to have clothed and peopled the earth, and that there must have been at each past epoch, as there is in the present, a due relation between the physical condition of the earth's surface and the vital necessities of the beings living upon it. The great practical deduction is this,—that, as the existence of certain assemblages of organic beings must have depended on the physical conditions of the earth's surface at the time of their existence, the discovery of their relics in the strata of the earth indicates the contemporaneous condition of its surface, and either encourages or discourages the hope of discovering the relics of other organisms.

It is thus that the Fossils of the Carboniferous, Triasic, Oolitic, or Cretaceous Periods, when found in any strata, lead us to search for other substances which have been found elsewhere associated with them; and they thereby become practical and economic agents of the highest importance. When therefore it is said that coal may be expected in the Carboniferous strata, nothing more is affirmed than this,—that the conditions of the surface were at that epoch favourable to the accumulation of those vegetable remains which have subsequently, by fossilizing agencies, been converted into coal.

The study, then, of Fossils is intimately connected with that of ordinary Natural History; and when the magnitude of its researches, extending as they do to epochs so remote that we cannot measure their antiquity, is considered, the student will no longer be surprised to find that it has become a distinct science under the designation of Palæontology. This study exhibits to us a variety of new and strange forms, both in the animal and vegetable kingdoms, which have long since been either greatly modified or have passed away: and it also proves that at successive epochs the assemblages of organic beings have been totally different in their specific characters from those now living, though in no instance created on principles of life different from those developed in existing organisms. A discovery so remarkable naturally led to the opinion that whole races of animals and plants had been swept away at successive epochs, and their places supplied by others newly created. This idea was

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accompanied by another equally plausible; namely, that a certain elevation in the standard of creation was perceptible from the earliest formations onwards to the more recent, when Man, as the most highly organised of the animal creation, was introduced. These favourite ideas are now giving way, and Palæontologists are more disposed to regard organic creation as one great whole, and what appear to be new species, and even new genera, to be merely the results of such modifications as time and the changes in the physical conditions of the earth may have worked on the first created animals and plants. The value of Palæontology in reference to Geology remains, however, unaffected by this alteration of opinion, as successive formations are equally characterised by different animal and vegetable forms, whether they are looked upon as new creations, or as mere varieties of old.

Some of the results which may be derived from this fact were ably set forth in the tables of Bronn's 'Index Palæontologicus,' made known to English readers by Professor John Nicholl. Before referring to them, the following explanatory Table of Formations may be extracted from his work:—

I. Carboniferous Period.	*a.* Lower Silurian. *b.* Upper Silurian. *c.* Devonian. *d.* Mountain Limestone. *e.* Coal Formation. *f.* Lower New Red Sandstone. *g.* Zechstein.
II. Trias Period.	*h.* St. Cassian Beds. *i.* Variegated Sandstone. *k.* Muschelkalk. *l.* Keuper.
III. Oolite Period.	*m.* Lias. *n.* Oolite. *o.* Kimmeridge Clay. *p.* Wealden.
IV. Cretaceous Period.	*q.* Neocomien. *r.* Greensand. *ſ.* Chalk.
V. Tertiary Period.	*s.* Nummulite Formation. *t.* Calcaire grossier. *u.* Middle Tertiary. *v.* Molasse. *w.* Upper Tertiary. *x.* Diluvial.
I.—V.	*y.* All fossil species together. *z.* Living.

In this preparatory Table it will be observed that the Carboniferous Period is made to include as sub-sections the Silurian and Devonian below, and the Lower New Red Sand-

stone and Zechstein above the ordinary Carboniferous formation. Doubtless this arrangement depends on two principles: first, that judging from the analogy of the world as it exists, evidence of the existence of land ought to be accompanied by those of mature action under all its varieties; and secondly, that there is a sufficient gradation between the organisms of these several sections to warrant their formation into one whole.

The object in referring to the Tables being in this Essay a practical one, many of the speculative reasonings which might be founded upon them will not be brought forward in a detailed manner. It is right, however, to allude to some of them before submitting the Tables for consideration. The duration of species is a subject of great interest, whether viewed as a geological or as a zoological question. It is known to us as a fact dependent on a great Law of Nature, that each individual has an average duration of existence, varying in extent with different species; but it has been asked whether species also have or have not a definite duration of existence—whether, in short, a species would continue to exist for an indefinite time, unless cut short by some alteration in the conditions of those natural forces to the influences of which it is exposed. If species have a limited existence, they must necessarily die out, independently of cosmical changes, unless those changes have been so regulated as to correspond with the exact duration of a species, assuming that the lives of all species are uniform in duration. And still more certainly must the disappearance or death of species be partially independent of such changes, when it is assumed that the duration of their lives is variable.

To determine the question of a fixed duration of life of species from the existing creation is almost impossible, as it requires a knowledge of the past as well as of the present, to an extent which has not yet been attained. It is indeed known that some species have disappeared within the range of historic relation, but as most of these have fallen under the destructive agencies of Man, they are not normal, but rather abnormal events. Geology, however, may be expected to aid in solving such a question, as it sets before us the records of the most remote past with a distinctness equal to those of the days only just gone by.

The first belief of the Palæontologist was assuredly that the species of every geological formation were peculiar to it alone, but the most warm advocates of such a theory have gradually so far modified their views as to admit that some few species have occasionally lived beyond the termination of one formation, and passed into another. Bronn has estimated the proportional number which have thus escaped destruction at ·12, and has estimated, therefore, the average duration of life in species at 1·12 a formation. It is manifest that this can only be received as the expression of a fact, namely, that species have on an average lived 1·12 formation, not as a proof that the *natural* life of a species, or, at least, of its maintenance of the same form of individuality, was limited to that extent of duration. When in this manner species have survived the great cosmical changes which destroyed the great mass of organic beings co-existent with them in a previous formation, have continued to live with undiminished vigour in a second formation, and have at length died away in the heart of that formation, it may fairly be presumed that they have disappeared in conformity with a Law of Nature which limits the duration of each species, or its continuance in some particular form, to some definite period. The scientific interest of this result renders the rigorous examination of all those species which are considered common to more than one formation most desirable; and in deciding on the question the Palæontologist should remember that colour, so important a character in recent objects, is deficient in those he is called upon to examine.

I. REVIEW OF THE FOSSIL SPECIES

	I. Carboniferous Period.							II. Trias Period.			
	a	*b*	*c*	*d*	*e*	*f*	*g*	*h*	*i*	*k*	*l*
I. *Plantæ.*	...	...	55	2	879	52	29	...	31	5	62
Cellulares	...	...	6	...	13	1	14	...	...	1	1
Vasculares	...	...	49	2	866	51	15	...	31	4	61
Monocotyledones	...	...	49	2	772	49	13	...	22	1	45
Dicotyledones	...	...	...	...	94	...	2	...	9	3	16
Monochlamydeæ	...	...	...	...	21	...	2	...	9	1	16
Corollifloræ	...	...	...	...	...	...	...	...	...	...	...
Choristopetalæ	...	...	...	...	2	...	...	...	...	...	...
Dubiæ	...	...	...	...	71	2	...	...	...	2	...
II. *Phytozoa.*	36	223	228	263	1	...	17	128	1	19	2
Pseudozoa	...	...	...	...	...	...	...	...	...	...	...
Amorphozoa	1	13	9	...	...	...	...	44	1	2	1
Polygastrica	...	...	...	1	...	...	...	...	...	...	...
Polypi	29	145	137	156	...	...	16	35	...	3	...
Foraminifera	...	...	...	9	...	...	...	...	...	...	...
Bryozoa	12	61	56	64	...	...	13	9	...	1	...
Anthozoa	17	84	81	83	...	...	3	26	...	2	...
Entozoa	...	...	...	...	...	...	...	...	...	...	...
Acalephæ	...	...	...	...	...	...	...	...	...	...	...
Echinodermata	6	65	82	106	1	...	1	49	...	14	1
Stelleridæ	6	65	82	106	1	...	1	9	...	13	1
Echinidæ	...	...	...	...	...	...	...	40	...	1	...
Fistulidæ	...	...	...	...	...	...	...	...	...	...	...
III. *Malacozoa.*	260	416	979	809	143	7	94	603	38	109	26
Tunicata	...	...	...	...	...	...	...	...	...	...	...
Brachiopoda et Rudistæ	151	148	131	199	4	...	35	43	1	10	2
Pelecypoda	25	69	287	186	70	7	44	129	30	71	10
Pteropoda	1	10	13	1	1	...	...	...	...	...	...
Heteropoda	10	24	28	35	7	...	...	...	...	...	...
Protopoda	...	...	4	3	1	...	...	4	...	2	...
Gasteropoda	38	71	246	248	16	...	14	341	6	26	14
(Ctenobranchia	34	68	230	222	15	...	13	335	5	21	9
Cephalopoda	35	94	270	137	44	...	1	86	1	18	...
IV. *Entomozoa.*	218	264	94	43	18	...	4	6	3	12	1
Vermes	4	7	8	10	...	...	1	6	...	4	1
Crustacea	214	257	86	30	10	...	3	...	3	8	...
Cirripedes	...	...	1	...	...	...	...	...	...	...	...
Entomostraca	214	257	85	30	9	...	2	...	1	3	...
Malacostraca	...	...	...	...	...	...	1	...	2	4	...
Myriapoda	...	...	...	...	...	...	...	...	...	...	...
Arachnidæ	...	...	...	...	2	...	...	...	...	...	...
Hexapoda	...	...	...	3	6	...	...	...	...	...	...
V. *Spondylozoa.*	...	7	110	65	80	17	49	4	12	50	77
Pisces	...	7	110	65	78	11	42	4	5	37	58
Leptocardii, Cyclostomi et Dipnoi	...	...	...	...	...	...	...	...	...	...	...
Elasmobranchii	...	7	38	63	27	...	11	2	1	23	40
Ganoidei	...	...	72	2	51	11	31	2	4	14	18
Teleostei	...	...	...	...	...	...	...	...	...	...	...
Reptilia	...	...	...	...	2	6	7	...	7	13	18
Batrachii	...	...	...	...	...	...	...	...	...	...	...
Ophidii	...	...	...	...	...	...	...	...	...	...	...
Saurii	...	...	...	...	2	6	7	...	7	13	17
Chelonii	...	...	...	...	...	...	...	...	...	..	1
Aves	...	...	...	...	...	?	...	...	...	...	...
Mammalia	...	...	...	...	...	?	...	...	...	...	1
Animalia	514	910	1411	1180	242	24	164	741	54	190	106
Animalia et Vegetabilia	514	910	1466	1182	1121	76	193	741	85	195	168

IN COMPARISON WITH THE RECENT.

III. Oolite Period.				IV. Cretaceous Period.			V. Tertiary Period.						I.—V.	Living.
m	*n*	*o*	*p*	*q*	*r*	*f*	*s*	*t*	*u*		*w*	*x*	all species together.	*z*
71	152	2	16	...	77	7	10	136	319	110	48	4	2055	69,403
9	46	...	1	...	22	5	9	4	34	19	4	...	188	9100
62	106	2	15	...	45	2	1	132	285	91	44	4	1867	60,303
32	57	...	9	...	14	...	...	132	31	12	3	...	1139	10,629
30	49	2	...	...	31	2	1	108	254	79	41	4	728	49,674
30	42	2	6	...	14	...	...	28	122	38	23	4	358	3246
...	...	...	...	...	...	1	...	...	13	14	1	...	28	23,900
...	1	...	...	...	3	...	...	74	68	27	9	...	175	22,528
...	6	...	...	...	14	1	1	6	51	...	8	...	167	...
29	579	16	2	149	270	1162	35	383	476	502	412	278	4895	4818
...	...	...	...	...	...	6	...	1	...	...	...	...	2	50
...	81	...	...	18	50	108	...	12	6	47	9	30	461	250
...	...	...	...	...	...	19	...	1	...	369	29	223	672	500
3	221	9	...	54	112	673	3	269	390	77	365	21	2528	1810
...	28	...	...	14	10	254	2	97	184	65	220	10	893	1000
...	26	1	...	27	42	323	...	79	129	4	51	3	810	380
3	167	8	...	13	60	96	1	93	77	8	94	8	825	430
...	...	...	...	...	...	...	...	...	...	...	...	...	...	1500
...	...	...	...	...	...	...	19	9	7	...	2	...	43	210
26	276	7	(2)	77	108	289	13	91	73	9	61	4	1189	498
17	92	1	(1)	4	6	36	...	6	3	2	5	...	416	286
9	182	6	(1)	73	102	253	13	84	70	7	56	4	770	146
...	2	...	...	...	...	...	...	1	...	...	...	...	3	66
533	1455	242	102	751	566	1500	39	2125	2725	783	1609	642	13,885	11,482
...	...	...	...	...	...	...	...	1	...	...	...	...	1	71
24	80	3	1	61	26	227	1	13	6	...	23	4	1146	48
212	786	173	77	336	279	697	25	705	783	164	556	189	4836	2413
...	...	...	...	...	...	...	...	2	8	...	2	8	41	62
...	...	...	...	...	1	...	...	...	...	...	..	...	23	85
2	8	...	...	8	8	13	...	32	24	1	34	8	120	64
81	300	53	24	135	125	415	12	1354	1892	218	984	439	6110	8673
79	275	52	23	130	122	395	12	1170	1540	152	853	300	5281	(5520)
214	281	13	...	211	127	146	1	18	12	...	4	...	1546	128
50	256	7	69	35	28	114	11	85	251	1381	91	9	2885	67,360
9	58	6	...	19	16	61	6	49	27	1	22	5	292	770
10	152	1	12	16	10	53	5	36	46	14	67	3	894	791
...	4	...	...	4	3	20	...	6	23	1	39	2	87	107
1	16	...	11	7	...	20	...	14	13	2	23	1	563	143
9	132	1	1	5	7	13	5	16	10	11	5	...	244	541
...	2	...	...	...	...	...	...	...	...	14	1	...	17	200
...	1	...	...	...	...	...	...	...	4	132	...	...	131	600
31	43	...	57	...	2	...	...	...	174	1220	1	1	1551	65,000
172	278	42	60	10	70	161	2	367	279	311	110	488	2701	18,085
130	222	27	43	10	68	152	2	266	90	54	54	5	1461	8000
...	...	...	...	...	...	...	...	...	...	...	...	...	...	11
26	49	12	23	5	18	80	...	76	56	24	34	...	550	221
104	172	15	19	5	7	28	2	19	...	5	4	...	572	30
...	1	...	1	...	43	44	...	171	34	25	16	5	339	7738
41	53	15	17	...	5	9	...	33	59	74	8	24	384	1055
...	...	...	...	...	...	...	...	...	35	15	4	12	65	175
...	...	...	...	...	...	...	...	4	3	8	2	2	14	300
40	48	10	12	...	5	9	...	8	8	13	...	4	206	460
1	5	5	5	...	...	...	...	21	13	38	2	6	99	120
...	...	...	...	...	2	...	...	11	25	5	...	101	148	7000
1	3	...	...	...	...	...	...	57	105	178	52	358	708	2030
784	2568	307	233	945	934	2937	87	2960	3721	2977	2222	1417	24,366	101,745
855	2720	309	249	945	1011	2944	97	3096	4040	3087	2270	1421	26,421	171,148

The Table here printed is one out of five which were quoted in the first Edition. Short as the time has been since their publication, new discoveries have materially modified their results, and it is necessary to point out the difficulties which are inherent in such calculations.

It is with the present creation that we desire to compare the creation of each successive epoch ; but as yet the examination of existing organisms is imperfect. Cuvier believed that the surface of the earth had been so well explored, that there was little hope of many new species of large animals being discovered ; but though it is true that many *very large* species have not been found, the lists of Mammalia, the highest class of animals, have been extended, since 1829, from 800 to more than 2000 species. The Birds have never been completely described, and the works on Fishes have yet to be finished. Count Dejean has about 30,000 species of Coleoptera alone in his collection,—a number which is so greatly disproportionate to that of the species of other orders of insects in his collection, although in nature they are known to be in nearly equal proportion, as to indicate the still imperfect state of our knowledge as to the totality of insects. And can it be doubted that, were the inquiry extended to every branch of the animal and vegetable kingdoms, the imperfection of our knowledge, even of the present creation, would become still more manifest, and it will be felt that the proportion between the Fossil and recent species given in the Table, can only be considered an approximation to the truth.

But there is another difficulty which should be kept in view in comparisons between the past and present creations. In investigating the present conditions of organic and inorganic existence, the inquiry is extended laterally over the surface of the earth, and, as it proceeds, adds continually to the amount of facts which are all related to the one history, namely, that of the earth in its present state. How different is the course of inquiry when directed to the investigation of any former condition of the earth ! It is then extended laterally only in a very imperfect and interrupted manner, as the outcroppings of a formation which was once the surface of the earth appear only here and there, the greater portion of it having been thrown down by internal convulsions of the earth, and buried under the matter of succeeding epochs. When, therefore, the Table states that 514 species of animals have been discovered in the lower Silurian, 910 in the upper Silurian, 1411 in the Devonian, 1180 in the Mountain Limestone, 242 in the Coal Formation, and 24 in the lower New Red Sandstone, and 164 in the Zechstein, whilst in the existing period 101,745 species have been described, it would be erroneous to conclude that the earth of the lower Silurian epoch only supported the $\frac{1}{198}$th part of the number of animals supported by the present earth, and the lower New Red Sandstone less than the $\frac{1}{4000}$th part. On the contrary, if the very limited extent of those portions of the earth's surface of these epochs submitted to our observation be taken into consideration, we shall have reason to feel surprise at the number of species known to us ; and when we further consider the numbers of individuals found in some fossil localities, we shall doubtless adopt a far higher estimate of the extent of organic existences in those remote epochs. If, indeed, the number of species found in any geological formation were compared with the extent of surface of that formation known, the estimate would probably in some cases rather exceed than fall short of the numbers of existing organisms : for example, if it were assumed that $\frac{1}{50}$th part of the surface of the earth at the Cretaceous epoch had alone been examined,—an area surely very much beyond the true proportion,—the total number of animals might be estimated at nearly half as much more than the number at present living.

But there is another important difference in the mode of investigation. We know the animals and vegetables of the present creation by the study, with a few excep-

tions, of living individuals; we know those of past creations by the study of their dead exuviæ; and in this difference is found an ample explanation of the absence from fossil faunæ and floræ of a multitude of genera, which, from the perishable character of their substance, cannot be expected to leave any permanent relics behind them. The natural habitat of most fossil species indicates the necessity of caution in reasoning on an imperfect fauna, which in our opinion ought not to be ascribed to the absence of certain classes of animals in the fossil epochs, but rather to the improbability of finding their relics in deposits such as those we examine.

A very limited local deposit of the Oolitic period, the Stonesfield slate, gave to light three species of the Marsupial order, an order now of very limited distribution, and thereby brought into strange connection the fauna of that remote epoch with the existing fauna of Australia. If the minute patch which produced so great a scientific treasure be compared with the whole extent of the Oolitic formations already known and studied, how small will appear the chance that such a discovery should ever have been made; and yet this fact is sufficient to demonstrate the truth, that warm-blooded Mammals of the Marsupial order did exist at the Oolitic period; and as the genera belong to the insectivorous type of the order, the fact proved in anticipation that insects must also have existed: and this deduction has been confirmed by the discovery of their relics in the Oolitic strata. Nor is this all; for with Professor Owen we must also assume, that the existence of small quick-breeding Marsupials of an insectivorous type justifies us in believing that the other types of that great order existed also, and that the harmonies of animal life were maintained then as now. Can it, for instance, be doubted that the large carnivorous Marsupials were then in existence, to prey upon the small and quickly multiplying insectivorous species? Such are the remarkable truths brought home to our convictions by the accidental and almost improbable discovery of a few fossil fragments, and which would have remained unknown had not that discovery been made.

It will be observed that the author of the 'Index Palæontologicus' carries back the existence of Mammals to the Keuper or newer member of the Trias; and Professor Owen admits traces of Mammalia and foot-prints of Birds at that period; it cannot therefore be said that no Mammals existed in the Cretaceous epoch, but rather that the same fortunate chance which gave, as it were, a glimpse at this higher member of the fauna of the Oolites is only wanting to display to us animals of equally high organisation in the Chalk. It is thus that the fauna of each of these remote epochs may be built up,—speculatively, it is true, but yet reasonably,—from often isolated individuals, just as in the hands of the great Cuvier the whole body of an extinct animal was first restored from the examination of a few of its fragments.

The caution necessary in deducing a too general determination of the absolute organic condition of the earth at each geological epoch will be further illustrated as we proceed with those more partial comparisons which are clearly within the power of the Geologist, and which will be here commenced by an examination of Table I.

1. *Carboniferous Period.*—The two great divisions of the Silurian system are characterised in this list by an absence of vegetable fossils; and though this deficiency may in part be accounted for by the metamorphic condition of a large portion of the strata, and cannot be admitted as a proof that no land plants existed, it certainly justifies the Geologist in assuming that these deposits were essentially marine, whilst the character of their fossils indicates some curious peculiarities in their distribution. Taking for example the upper Silurian, in which the fossils are more largely developed, the whole number of animals already known is stated to be 910, or, compared with the reduced number, 27,045, about $\frac{1}{30}$th of the number now living, whilst in some of the great classes the proportion is very different. In the Phytozoa

or plant-like animals, the proportion of upper Silurian to the recent, leaving out Entozoa and Acalephæ, is $\frac{1}{14}$th; in the Malacozoa it is about $\frac{1}{28}$th; but this very low proportion may be readily accounted for by the great number of land and fresh-water Testacea which form part of the total of recent animals. If, indeed, special classes of this division be selected, the proportion assumes a totally different aspect; as, for instance, the Brachiopoda amount to 148 species, or three times the number of living species, and the Cephalopoda to 94, or about $\frac{3}{4}$ths of the living. If, therefore, the whole of the Silurian world had been fully investigated, in these two classes there would have doubtless been a vast preponderance of numbers in its favour,—a fact of great interest, when the high position of the Cephalopoda in the animal kingdom is considered.

In the Entomozoa, from reasons already stated, the comparison can only be fairly made between the fossil and recent Crustacea, and the proportion of the former to the latter is so high as $\frac{1}{3}$rd, whilst in the Entomostraca the number of fossil species is nearly double that of recent. In fact, the Malacostraca have not as yet been noticed in this ancient fossil fauna; and this apparent deficiency, which occurs, though in a less degree, in all the formations except the Oolite, is very difficult of explanation; but in the latter case, as in the recent fauna, the species of Malacostraca appear to have increased just in proportion to the diminution of those of the Entomostraca, and it is therefore highly probable that the careful comparison of the numbers of each in local faunæ of existing species would afford a clue to the laws which have regulated their distribution. It may be observed that in no other formation is the number of Entomostraca so great, and that the remarkable family of Trilobites distinguishes the Carboniferous epoch from all others, and more especially serves as a guide to the Silurian, to which it has supplied a vast number of genera and species,—for some of which, see Geology Plate VIII. The researches of M. Barrande have thrown additional light on the natural history of Trilobites, and his investigation of the Geology of Bohemia is a striking illustration of their importance for the determination of geological epochs. M. Barrande describes no less than 129 species of Trilobites, which it will be observed is more than half of the number recorded in Bronn's Table; so that even by this one locality it may be presumed that a large extension of the Silurian fauna has been effected,—a conclusion strengthened by the general total of the Bohemian fossils, which amounts to 600 species, a number nearly equal to half of that given by Bronn. Whilst, however, the number of species of Trilobites is so great, there are but few identical with those previously recorded; and it is therefore from the occurrence of such remarkable genera as Paradoxides, Battus, and Trinucleus, that the identity of formation is determined. In some of the sectional divisions of the Bohemian strata, Trilobites exist abundantly, to the comparative exclusion of other fossils; and this has been partly ascribed to the nature of the water, as being assumed to be more charged with siliceous matter than was suited to the development of Mollusca; but such reasoning appears to be purely speculative. At the Silurian epoch, as at the present, the several peculiarities of the sea-coast, its bays and estuaries, must have influenced the character of its organic inhabitants; and whilst in muddy bays and seas giving rise to the geological formation of slates, multitudes of Crustacea may have lived, there can be no doubt that Cephalopoda and Mollusca were equally flourishing in other portions of the same sea, where the physical conditions were more in conformity with their vital necessities. The relics of large Cephalopoda and of many of the Brachiopoda would be naturally sought for in those deposits which had been formed in the regions where they peculiarly existed; and it is therefore in deep sea deposits, or in the massive limestone strata, that they are principally found. In Plate VIII. some of them have been figured. It may be safely laid down as a rule, that the occur-

rence of Trilobites in abundance is strong presumptive evidence that the strata belong to the Silurian epoch, and if they can be allocated to any of the well-known genera of that formation, all difficulty of determination is removed. In the calcareous deposits, some of which have doubtless been contemporaneous with the slaty, the Cephalopoda, Brachiopoda, and Zoophytes will afford a clue to the identification of the strata nearly equally decisive, though not so easy and striking. The late discovery by Mr. Salter of a Silurian Chiton is a remarkable fact, as tending still further to place the ancient fauna in harmony with the recent.

c. Devonian.—This formation, so remarkable for its sandy, pebbly, marly, and schistose deposits, occupies a transition place between the Silurian and true Carboniferous formations, and is often therefore difficult of determination. The condition of the Silurian Crustacea found in this formation is sometimes such as to indicate their exposure to attrition, and consequently to induce a belief that they are not *bonâ fide* Devonian fossils. The total number of species of animals has increased to 1411, and whilst the Crustacea, so strikingly characteristic of the Silurian, have diminished from 257 to 86, the gasteropodous Molluscs have risen from 71 to 246, and the Cephalopoda from 94 to 270,—so as to more nearly resemble in distribution the true Carboniferous than the Silurian fauna. The Devonian has, however, its own peculiar characteristic in the richness of its Ichthyology, though the heterocercal fish lived in the upper Silurian epoch,—no less than 110 species of fishes having been recorded at the date of the Index. The local nature of the marly or clayey beds in which the remains of fishes might be preserved renders it rarely possible to use them for stratigraphical identifications, and dependence therefore must principally be placed on the Mollusca. (See Plate IX. 'Geology.')

d. Mountain Limestone and Coal Formation.—These two divisions constitute the true Carboniferous system, the two members of which exhibit very striking peculiarities. In the Mountain Limestone, the Brachiopoda number no less than 199, many of which are strikingly characteristic, whilst the Coal strata have only 4,—and generally the Mollusca in the former number 809, and in the latter only 143. The great peculiarity of the Coal series is, however, the richness of its flora, which, coupled with the almost total absence of the Phytozoa, and the appearance, for the first time, of reptiles of the Saurian type (Archigosaurus Decheni), can leave little doubt on the mind that the conditions of deposit were very different from those of the Mountain Limestone. The one has every characteristic of a deep sea deposit, the other of estuary and almost lacustrine deposition. Göppert has shown that the formation of coal may be imitated mechanically, and has noticed this curious distinction, namely, that by operating on the vegetable structure alone, substances analogous to the brown or tertiary coals are produced, whilst by adding sulphate of iron a true coal is the result. This distinction points to a peculiarity in the vegetables which gave rise to the coal deposits, and justifies him in his opinion that the sulphuret of iron so common in the beds of coal proceeded from the plants which produced them. Sigillariæ, Lepidodendra, and Calamites are characteristic of the true Coal formation.

The frequent occurrence of the genus Cypris in the shales of the Carboniferous system is also strongly illustrative of the manner of their formation.

f. g. Permian System, comprising lower New Red Sandstone and Zechstein or Magnesian Limestone.—This section of the New Red Sandstone is placed by Bronn in the Carboniferous system, and in this opinion many Geologists concur, as the fossils of the Magnesian Limestone exhibit a great similarity of character, more especially in the occurrence of the genera Productus and Spirifer. In the marly beds of the Sandstone many fishes have been found, and there is still a considerable proportion of plants. In the Magnesian Limestone section the total number of fossils is much

greater than in the lower Red Sandstone, but whilst it has contributed seven times the number of animals to its fauna, it possesses scarcely more than one-half the number of plants. This great difference is strongly marked in the Malacozoa, the Magnesian Limestone having produced 94 species, and the Sandstone only 7; but there can be little doubt that this absence of fossils from the sandy strata is the result of their disintegration, such deposits being peculiarly unfavourable to the preservation of organic remains. Between the Mountain and the Magnesian Limestones the Table exhibits one very marked difference, namely, the abundance of Echinodermata in the former (some of which have been figured in the Plates to 'Geology') and their comparative absence in the Magnesian. The great development in Russia of this geological section has led to the adoption of a distinct name for it,—the Permian system,—but whilst the great similarity of its fossils closely associates it to the Carboniferous, it should be remembered that the occurrence of carbonate of magnesia is only the result of the greater development of a mineral which often enters into the composition of the Mountain Limestone. The greater number of reptiles is perhaps sufficient to indicate a difference in the conditions of deposit, more especially when combined with the deficiency of Echinodermata; but that there is more analogy between the Permian and Carboniferous epochs than between the Trias and Permian may be further proved by reference to the fauna of the Trias, which assuredly in the Muschelkalk approaches to the character of the Oolitic fauna, just as that of the Zechstein approaches to the Carboniferous. And were any further proof required, it is found in the floræ of the successive epochs, that of the Permian being, like the Carboniferous, distinguished by the predominance of Ferns and Lycopodiaceæ, whilst the Trias, like the Oolitic epoch, abounds in Cycadeæ and Coniferæ.

h, i, k, l. Trias Period.—Leaving out of immediate consideration the St. Cassian Beds (*h*), which, as Bronn states, are only local, although they produce a sea fauna of probably more species than could be collected in a similarly limited space of our present sea bottom, the Trias exhibits a remarkable diminution in its organic contents. To account for this defect, it has been supposed that the great amount of oxide of iron was injurious to organic and more especially to animal life; but such a theory places a co-existing effect in the position of a cause. All sandy beds must be unfavourable for the preservation of organic remains, as the ready filtration of water charged with carbonic acid must promote their rapid disintegration; and, indeed, in this manner all the solid parts of many fishes have disappeared, although the impressions of their external coverings or scales remain as distinct as if they had been drawn from life. The frequent association, also, of gypsum in large quantities with the salt-beds of this formation may also suggest other causes;—its occurrence is not improbably of secondary origin. In England, the Muschelkalk is only very faintly represented, if it exist at all, but on the Continent it forms the central member of the formation. By the occurrence of the ammonitic type of Cephalopoda it approximates to the next period, and it may well be doubted whether a formation in which arenaceous beds so strongly predominated should be kept distinct, as such a character bespeaks a partial origin, and indicates a portion rather than a whole. It is well known that the footsteps of a remarkable animal long noticed on the beds of the New Red Sandstone have been traced to the Labyrinthodon, a reptile between the Saurian and Batrachian types, whose remains have been found in the Muschelkalk; similar footsteps have been discovered in Pennsylvania, in strata considered of the age of the Old Red Sandstone. Mr. Lea has called the animal of which these footsteps are as yet the only records, Sauropus primævus. The Chelonians or Tortoises appear for the first time in the list, affording another analogy with the Oolitic period. The flora, according to M. Adolphe Brongniart, affords a more certain element of comparison, as it no longer, like the

Permian, exhibits strong analogies with the Carboniferous, but differs from it in a marked manner.

That distinguished botanist points out that two causes of difference must be admitted in fossil floræ, the one due to change of epoch, the other to difference of geographical position,—just as in the present time there are local variations, a forest of Pinus sylvestris growing in Germany, one of Abies taxifolia in the Vosges, of Picea excelsa in the Jura, and of Pinus pinaster in the Landes. This is very evident in the flora of the Permian system; but though the local floræ of the epoch were specifically varied, they possess a common relation to the flora of the Coal formation. A great botanic change had, however, taken place, and the Trias and Oolitic periods were linked together by the prevalence of plants belonging to another great division of the vegetable kingdom, the Gymnosperms. This difference in the floræ of successive epochs, and the equally striking differences between the fossil and recent floræ, should be sufficient to satisfy even those who still hesitate to receive their evidence in establishing such successive epochs. Brongniart, for example, states that the Coal formations of Europe have as yet produced only 500 species, whilst the flora of Europe includes about 11,000; but if the Ferns of the two periods be compared, the disparity is in the other direction, as the Coal formation of Europe has already produced 250 species, and the whole of Europe now only produces 50. In Plate X. of 'Geology' some of the most remarkable fossils of the Trias are figured. As this is, as it were, the turning-point from the more ancient organic condition of the earth's surface, it may be well to abstract briefly some of the conclusions of Mr. W. King in his recent Monograph of Permian Fossils. The genus Productus, so characteristic of the fauna of the Carboniferous epoch, and well exhibited in the Permian, appears also in the marls of St. Cassian,—so that some doubt may be felt as to the age of the latter. In the Permian system, remains of the tetrabranchiate division of Cephalopoda, or of the Cephalopoda with external shells and internal siphons, have alone, as yet, been found; whereas Rhyncolithes, or the mandibles of Cuttle-fish, or of dibranchiate Cephalopoda, occur in the Trias, and thus prepare the way for the Belemnites of the Lias. This commencement (Bellerophon is of doubtful analogies) of a great series of remarkable animals, which in the existing epoch comprises so many genera and species (our Sepia, Loligo, Argonauta, &c.), deserves especial attention, and should be always compared with the present almost evanescent condition of the other great branch, the tetrabranchiate, now represented by only two species of the single genus Nautilus.

There are, however, many difficulties in settling the exact zoological relations of strata, standing as these do on the limits of two great divisions. The absence of Trilobites from the Permian rocks is a strong negative difference between them and the Carboniferous; but this may be in great measure ascribed to difference of physical conditions. In the Fishes there is a close generic though not specific connection between the Permian and Carboniferous, whereas the approximation is very much less between the Permian and Triasic. In the Reptiles, as yet, the comparison can only be considered imperfect; as the impressions of supposed Labyrinthodonts have been noticed by M. Conrad in the Devonian system of the United States, and should the determination be verified, the reptile character of the Trias will be bestowed on rocks of a more ancient date even than the Coal, as it is to a certain extent on the Coal series itself by the labyrinthodont forms (as they are considered by Von Meyer) of Archegosaurus and Sclerocephalus. On the whole, there is much reason to consider the Permian a portion of the Protozoic, the Trias a portion of the Deuterozoic period, as the appearance of the ammonitic forms of Cephalopoda in the Trias is of itself a powerful argument for approximating it to the Oolitic rather than to the Carboniferous

system; far more powerful than the continuance of a few forms of the preceding epochs would be for the opposite determination.

m, n, o, p. Oolitic Period.—This great member of the Deuterozoic formations is replete with objects of the highest interest. It has been already stated that, leaving out of consideration the recently supposed occurrence of Mammals in the Keuper, the Oolitic formation has produced the first Mammalian relics, exhibiting at this early epoch examples of the Marsupial type which is now so characteristic of Australia—a region widely distinguished both by its fauna and flora from other parts of the known world. In like manner its numerous reptiles, the fish-like Saurians (Ichthyosauri and Plesiosauri), and the flying Saurians (Pterodactyli) constitute a rich and varied, but most strange assemblage of organic bodies. The beaks of supposed dibranchiate Cephalopoda have been noticed as occurring in the Trias, but with the Oolites they enter distinctly into the fauna, and afford examples of seven genera, one of which extends into the Chalk, another reappears in the Tertiaries and extends into the recent epoch, and four more, after apparently disappearing with the Oolites, reappear in the recent epoch. Of all these none is more remarkable than the genus Belemnites, which affords a close link of connection between the Oolitic and Cretaceous formations, just as the Trilobites and Producti of the Protozoic period did between the Silurian and true Carboniferous. M. Alcide D'Orbigny divides the genus into three sections, each characteristic of a geological division; namely,—1. Those with neither ventral nor lateral grooves, which are peculiar to the Lias or lower section of the Oolites; 2. Those with a ventral but not with lateral grooves, which belong to the upper Oolitic sections; 3. Those with a ventral and two lateral grooves, which belong to the Neocomien (or lower greensand) and gault sections of the Cretaceous formation. Of the Belemnites of the white or upper Chalk, M. D'Orbigny forms his sub-genus Belemnitella, which is characterised by an anterior notch, so that the species of this remarkable family have changed in form and character in the successive faunæ of the earth, and after having swarmed in such abundance during the Oolitic and Cretaceous periods, have totally disappeared with the latter from its surface. The changes which have taken place in the tetrabranchiate division of Cephalopoda are also most remarkable.

These Cephalopoda are divided by D'Orbigny into two great families; 1st, Nautilidæ; 2nd, Ammonidæ. In the first, D'Orbigny recognises the genera Nautilus, Aganides (Clymenis), Cyrtoceras, Lituites, Orthoceratites. All these appeared in great numbers and in very varied forms (including Phragmoceras) in the ancient fauna of the Silurian epoch; but, strange to say, the genus Nautilus alone occurs in the Oolitic and Cretaceous. The Aganides reappear in the Tertiary, but the genus Nautilus alone preserves to man a knowledge of the tetrabranchiate Cephalopoda of ancient worlds. The Nautilidæ are distinguished from the Ammonidæ by the straight or simply arched septa of their chambers, those of the Ammonidæ being lobed or digitated, and by a central or medial siphuncle, that of the Ammonidæ being dorsal (more properly called ventral).

The family of Ammonidæ contains seven genera, one of which only, namely, Goniatites, goes back so far as the carboniferous strata, of which it is a characteristic Cephalopode, at once appearing and ending in them. As the Goniatites have their septa formed with either angular or rounded lobes, and not with lobes of the foliated forms of the Ammonidæ, they are very distinct from them, though associated in the same family. With the Muschelkalk true Ammonites begin, though still with comparatively simple septa, but in the Oolites they attain highly digitated or ramified septa, and exhibit a number of species, these animals having been peculiarly abundant

at that epoch. It is scarcely necessary to refer in detail to other animals, though the genera Lima and Gryphæa are highly characteristic amongst the bivalves, and the genus Trigonia, now existing only in Australia, occurs to confirm, as it were, the analogies suggested already between the Oolitic and recent periods by the presence in the Oolitic strata of Marsupial Mammals. In the whole series of formations, none is more remarkable than the Oolitic, and it has been called, from the peculiarly rich development of its reptiles, the age of reptiles. The great marine Saurians, Ichthyosaurus and Plesiosaurus, have been already noticed, genera which seem to form a link between reptiles and fishes; but in addition to these, reptiles of the crocodilian type appear at this epoch. Some of these, Teleosaurus, Steneosaurus, Cetiosaurus, were, like the Gavials, fitted to prey on fishes, having long narrow jaws armed with slender, conical, sharp-pointed, and equal teeth: they were indeed mighty monsters, the jaws of the Teleosaurus Chapmanni exhibiting at least 140 teeth, and the bodies of some of the species of the two first genera being 18 feet long, whilst in the third genus some of the species attained an enormous bulk, the Cetiosaurus medius having possibly been 40 feet long, and others having almost rivalled the modern whales in magnitude. Passing, however, from the marine, only remarking that Saurians with true marine habits are now represented by only one species, the puny Amblyrhynchus of the Gallipagos Islands, we find that the land was equally replete with wondrous exhibitions of these gigantic reptiles, forming the Dinosaurians of Owen, which are called by him Crocodile-lizards, being distinguished both from the modern terrestrial and amphibious Sauria, and from extinct marine lizards. Of these the most remarkable are the Megalosaurus, the Iguanodon, and the Hylæosaurus. Professor Owen corrects the preceding estimates of the length of the Megalosaurus, which he considers excessive, and reduces it to 30 feet; but even this is sufficient to constitute an enormous creature, more especially as it was more elevated and bulky than ordinary Saurians. Of British Oolitic strata, the Stonesfield slate, Bath oolite, Cornbrash, and Wealden have produced specimens of this genus. The Hylæosaurus and Iguanodon are both from the Wealden, the latter having been discovered by Dr. Mantell, and called Iguanodon by Conybeare from the resemblance of its teeth to those of the living Iguana, though in other anatomical characters it is strongly distinguished from it. From the supposed analogies between this reptile and the Iguana, it was estimated that the Iguanodon might be from 75 to 100 feet in length, but Professor Owen, on apparently sounder principles, deduces the length of 28 feet, a magnitude still enormous. This extraordinary development of reptile forms has been ascribed to a defective condition of the atmosphere, but there appears to be more probability in the opinion of Professor Owen that these gigantic reptiles may have supplied the place of large predaceous mammals. Be this, however, as it may, the Oolitic fauna,—with its Marsupials associated with the genus Trigonia of conchiferous Molluscs, (as at the present epoch they are in Australia, the land of Marsupials,) with its Belemnites and Ammonites, many of large size, its insects, and above all with its gigantic reptiles, which people the land, the sea, and the air,—must always be distinguished amongst the records of former epochs, for its singularity and grandeur.

q, r, f. Cretaceous Period.—Although the mind must long linger with delight on the extraordinary fauna which the Oolitic period has placed before it, the interest which the Cretaceous fauna is calculated to excite is of no ordinary kind. In the genera Mososaurus, Leiodon, and Raphiosaurus, the Lizard-Saurians are represented, and Professor Owen states that below the Chalk he has not hitherto found any instance of a reptile possessing vertebræ with an anterior cup and posterior ball, or the ordinary ball and socket structure of existing species. Chelonians (Turtles and Tortoises),

which commenced in the Triasic and appeared also in the Oolitic period, occur in the Chalk, though not noted in the Table. They are referred by Professor Owen to the marine section, or to the true Chelonia.

Referring now to the Cephalopodous Molluscs as the most characteristic of both the Oolitic and Cretaceous periods, the Belemnites are continued from the Oolites in the two genera Belemnites and Belemnitella, the latter being characteristic of the upper Chalk. In the Tetrabranchiate division, the genus Nautilus produces a considerable number of species, and D'Orbigny gives as a characteristic difference between those of the Oolitic period and those of the Cretaceous, that in the former there are never deep transverse furrows, so that any specimen of Nautilus exhibiting transverse furrows or ribs, may be, with every probability, assumed to be cretaceous. Of the *family* of Ammonidæ the first trace had been observed in the Goniatites of the Carboniferous strata, but in the Muschelkalk (a member of the Trias) true Ammonites began to appear, and in the Oolitic period attained their highest development in numbers and variety of form. In the Cretaceous epoch they exhibit a variety and profusion nearly equal to that of the Oolitic, and are combined with several other generic forms of the ammonidic type, such as Hamites (which appeared first in the Oolitic period), Crioceratites, Scaphites, Baculites (which being, as it were, straight Ammonites, represent the Orthoceratites, or straight Nautili of the more ancient epoch), and Turrilites. D'Orbigny, in his 'Paléontologie Française,' has figured no less than 143 species of the genus Ammonites from the Cretaceous strata, so that the richness of the fauna of that epoch in such Cephalopoda is truly wonderful, and strongly contrasts with the poverty of our recent fauna.

It is of the highest importance to understand the actual geological distribution of Ammonites, as they are the most characteristic fossils of both the Oolitic and Cretaceous periods, and for this purpose it is desirable to study the classification of Von Buch, as improved by D'Orbigny.

1. Von Buch considers the Goniatites as a section of Ammonites, but they may be left out of the present inquiry, as the simply rounded and angular lobes of their septa at once distinguish them from all true Ammonites.

2. He places the Ammonites of the Muschelkalk or Trias in a separate section—the Cératites—as their septa, being much more simply lobed than in the subsequent sections, point them out as an intermediate group.

Species with one entire or simple dorsal (more properly ventral) keel.

3. *Arietes:* shell marked on the sides by simple radiating projecting ribs; back square, with a central keel; siphon prominent, placed on the dorsal keel; mouth prolonged into a beak; septa formed of uneven lobes and swells (saddles of Von Buch); dorsal lobe as deep, as wide, and longer than the upper lateral lobe: the lateral swell ascends higher than the others, and the dorsal swell is very short. This group is peculiar to the lower portion of the Lias.

4. *Falciferi:* shell compressed, having on the sides folds inflected forwards, and often forming an elbow in the middle of their length; no tubercles; back sharp, extending into a narrow keel which contains the siphon; mouth complete, having projecting points in the centre of each side; lobes of septa uneven; swells nearly even; dorsal lobe very wide, and its accessory lobe may be taken as the upper lateral; and is always much longer than the dorsal lobe. This group is peculiar to the upper beds of the Lias.

5. *Cristati:* shell compressed, and adorned on the sides by bifurcated ribs, which are inflected forwards, but do not form an elbow; with or without tubercles; back extending into a keel which contains the siphon; mouth perfect, prolonged into

a central beak; septa formed of lobes which are generally divided into uneven parts, and of even swells; dorsal lobe larger than the upper lateral; lateral swell less elevated than the rest; dorsal swell very high. This group is peculiar to the Cretaceous period.

Species with a channelled back.

6. *Tuberculati:* shell adorned on the sides with ribs and with tubercles which alternate on the sides of the back; back provided with a deep central channel; mouth complete, representing an elongated beak which corresponds to the dorsal canal; septa formed of lobes and swells divided into uneven parts; dorsal lobe shorter than the upper lateral lobe, and so narrow that it does not occupy the breadth of the dorsal canal. All the species of this well-defined group belong to the Cretaceous period.

Species with sharp backs not keeled.

7. *Clypeiformi* (D'Orbigny): shell compressed, generally smooth or very slightly ridged; back sharp or wedge-shaped, but without keel; whorls of spire large, and generally enveloping; septa divided into a great number of lobes formed of unequal parts and of swells formed of equal or nearly equal parts; dorsal lobe shorter than the upper lateral lobe; both swells and lobes wide and short. This group belongs to the Cretaceous period.

Species with the back projecting, and notched along the medial line.

8. *Amalthei:* shell ribbed on the sides, the ribs being slight and inflected forwards; the back sharp, and divided by transverse plaits or folds which form a notched surface; mouth provided with a central beak, the ancient condition of which may be traced in the notches on the back; septa formed of lobes and swells divided into uneven parts; dorsal lobe shorter than the upper lateral lobe. This group is peculiar to the Jurassic and Oolitic beds.

9. *Pulchelli* (D'Orbigny): shell elegantly marked on the sides by straight (not inflected) projecting ribs, which extend from one side to the other, forming on the back a compressed tubercle, so as to produce a series of crests, resembling cocks' combs; septa composed of lobes divided into uneven parts and of swells divided into even parts; dorsal lobe nearly equal in length to the lateral inferior one. This group belongs to the lower Cretaceous strata, the lower greensand and gault.

10. *Rhotomagenses* (D'Orbigny): shell with swollen square or oval whorls, which are adorned by projecting ribs, more or less tuberculated, the tubercles being arranged in four or five rows, one of which occupies the medial line of the back, and renders it more or less angular; septa formed of lobes and swells divided into equal parts; the dorsal lobe longer than the upper lateral lobe. This group differs from the Armati by having several rows of tubercles along the back, one of which is medial, by its equal lobes, and by its dorsal lobe, which is always the longest. All the species belong to the upper greensand of the Cretaceous epoch.

Species having a hollow back and tubercles on the sides.

11. *Dentati:* shell more or less smooth, adorned with ribs which are often bifurcated at the margin of the umbilicus, where they usually form tubercles: the ends of the ribs project on each side of the back, the middle of which is hollow; septa formed of lobes divided into unequal parts and of swells generally divided into equal parts; dorsal lobe equal to or shorter than the upper lateral lobe. All the species of this group belong to the lower portion of the Cretaceous system, viz. the lower greensand and gault.

12. *Ornati:* shell slightly swollen, with narrow back, bordered by tubercles; another row of tubercles at the depression of the spire towards the middle of the flanks; septa formed of lobes and swells composed of unequal parts; the dorsal lobe very much shorter than the upper lateral. A group exclusively belonging to the Oxford clay, a division of the Oolitic formation.

Species with the back more or less square.

13. *Flexuosi:* shell furnished laterally or at the margin of the umbilicus with a row of tubercles, and with another at each side of the back, the middle of which forms a slight projection. Between the two rows of tubercles of the sides are generally ribs which are slightly inflected forwards; septa formed of lobes divided into unequal parts and of swells divided into equal parts; the dorsal lobe shorter than the upper lateral one; the upper lateral very wide. A group belonging to the lower portion of the Cretaceous system.

14. *Compressi* (D'Orb.): shell generally very compressed, composed of large whorls closely enveloping each other, and having lateral ribs or striæ which are only slightly inflected, and form tubercles on the sides of the back; back narrow and square, as if truncated; septa composed of a great number of lobes divided into unequal parts and of swells frequently formed of equal parts; dorsal lobe very great, being much longer than the upper lateral lobe. A group belonging to the Cretaceous period, and extending over the whole of the greensand.

15. *Armati:* shell with square whorls, having on the sides of the back one row of projecting tubercles, and on the flanks one or more rows; back wide and square; septa composed of lobes formed of unequal parts and of swells formed of equal parts; dorsal lobe longer than or equal to the upper lateral lobe, the latter being placed in the middle of the flanks, and always narrow as regards the dorsal swell. A group peculiar to the Oolitic period, and specially to the upper members of it.

16. *Angulicostati* (D'Orb.): shell thick, with whorls almost round, though marked on each side of the back by a slight projection which renders this part nearly square; back much more narrow than the flanks; the ribs elevated, and alternately passing over the back from one side to the other; septa composed of lobes formed of unequal parts and of swells generally even: the dorsal lobe is much shorter than the upper lateral, and the auxiliary lobes are oblique towards the umbilicus. A group belonging to the lower portion of the Cretaceous system, and differing from the Planulati only by the square back.

17. *Capricorni:* shell with very convex whorls, adorned by bold simple straight ribs without tubercles or spines; back wide, often having a surface more extensive than that of the flanks; septa composed of lobes formed of unequal and swells of equal parts; dorsal lobe the largest; the lateral lobes wide. A group peculiar to the Oolitic period.

Species with rounded convex back.

18. *Heterophilli* (D'Orb.): shell compressed, formed of whorls which are almost always so far enveloping as to be rarely visible in the umbilicus: the sides are smooth, slightly striated or grooved; back narrow, and very convex; septa symmetrical, divided into a great number of highly ramified lobes, the parts of which are uneven, and of swells generally composed of equal parts; dorsal lobe almost always shorter than the upper lateral lobe. From the great number of branches of the lobes, the swells between them represent the form of leaves in a very striking manner. This group extends from the Oolitic period into the Cretaceous, but it admits of subdivision according to the unequal or equal parts of the swells; and

whilst the former section belongs exclusively to the Oolitic, the other is equally peculiar to the Cretaceous.

19. *Ligati* (D'Orb.) : shell compressed, generally smooth or only slightly waved, and usually marked at intervals by grooves or ribs which formed the margin of the mouth at its successive stages of growth ; back convex, sometimes a little compressed ; septa composed of lobes formed of unequal and of swells of generally equal parts ; the dorsal lobe shorter than the upper lateral; the last auxiliary lobes often oblique to the rear on approaching the umbilicus ; the swells very divided but never resembling leaves. A group peculiar to the Cretaceous period, and extending over the lower and upper greensand.

20. *Planulati:* shell discoidal, compressed, composed of whorls more or less cylindrical, adorned with striæ or crowded ribs, which towards the middle or at about two-thirds of the flanks divide into several branches, though not provided with knobs at the point of junction; back round ; septa composed of lobes always divided into uneven parts and of swells usually formed of even parts ; the dorsal lobe either longer or shorter than the upper lateral : the auxiliary lobes are obliquely directed backwards towards the umbilicus in a marked manner. A group which would be peculiar to the Oolitic period, were it not that three species of the lower Chalk, of which the lobes are only imperfectly known, are provisionally included in it.

21. *Coronarii:* a group which specially characterizes the lower Oolite. It is distinguished from the Planulati by having a knob or tubercle at the point where the ribs or striæ bifurcate; whorls elevated; septa composed of lobes divided into unequal and of swells formed of equal parts; the dorsal lobe shorter than the upper lateral; the auxiliary lobes oblique: the upper lateral lobe is outside of and the inferior lateral lobe within the tubercles.

22. *Macrocephali:* shell analogous in form, ribs or striæ, to that of the group Coronarii, with this difference, that it is often more swollen, and the tubercle, instead of being placed about the centre of the breadth of the whorl, is nearer the umbilicus, so that both the upper and lower lateral lobes are outside the tubercle, and not one within and the other without. The most swollen species proceed from the Oolitic strata, but the group itself extends into the Cretaceous.

23. *Frimbriati* (D'Orb.) : shell discoidal, composed of cylindrical whorls which are generally contiguous, without in any manner covering each other, and are either smooth or transversely marked at intervals by projecting ribs or by grooves which were the former margin of the mouth ; mouth circular ; septa symmetrical, formed of lobes and swells divided into equal parts, and always enlarged at their extremity and narrowed at their base ; dorsal lobe often the longest. This group, so well characterized, is found both in the lower portions of the Oolitic and of the Cretaceous periods : the greater number of species belong to the lower greensand, or base of the Cretaceous system.

It has appeared desirable to give these ample details on the highly important genus Ammonites, as it will often be necessary in geological researches, to seek the means of identification of strata in the several groups into which it is divisible, as in many cases those mineral differences which may assist in such inquiries, and are in some localities or countries well marked, disappear entirely in others. With the Chalk, Ammonites disappear, the upper section of the white chalk being deprived of them. In this interesting and varied family, therefore, of the most highly organized class of Mollusca (the Cephalopoda) the fauna of each successive formation possessed characteristic representatives, commencing with the Goniatites of the Carboniferous strata ; and D'Orbigny recognizes even characteristic forms in his three divisions of the Cretaceous system, assigning—

75 species to the Neocomien, or Lower Greensand.
42 do. to the Gault.
27 do. to the Chalk, including the Upper Greensand and true Chalk.

And so striking is this limitation of the forms to particular faunæ or epochs, that he thus remarks upon it: "After comparing thousands of these Ammonites from all parts of France, I have come to this important result, that it is not merely some species, as has been hitherto supposed, which are characteristic, but that all the species of Ammonites, without exception, are characteristic, and that all indicate with certainty the strata to which they belong, when the application of their evidence is made with a critical knowledge of the species."

To the Ammonites may be added other remarkable genera of Cephalopoda which are peculiar to the Cretaceous period :

Crioceras, differing from Ammonites in having the whorls, though in one plane, perfectly separate from each other, and not contiguous or enveloping. The lobes of their septa are always formed of unequal parts. D'Orbigny describes seven species, five of which are peculiar to the lower greensand, and two to the gault, the genus itself having had, therefore, a very limited range of existence.

Toxoceras, differing from Ammonites, as the whorls do not form a spiral, but are arranged like an oblique horn. D'Orbigny describes nine species, which all belong to the lower greensand, to which the genus appears restricted.

Scaphites : shell in the early stages of growth resembling Ammonites by its contiguous whorls, but then suddenly extending in a straight line for a considerable distance, when it is again bent back towards the spire. This genus only existed during the deposition of the upper and lower greensand, and D'Orbigny reduces the known species to three in number.

Hamites, separating from it those species which form the genus Ancyloceras (D'Orb.), is peculiar to the Cretaceous epoch, beginning with the lower greensand, abounding in the gault, and disappearing in the upper greensand. It is distinguished from Ancyloceras by having an irregular spire composed of elliptical whorls bent round, as it were, in elbows. The whorls are in the same plane, are never in contact, and are prolonged at each turn for some distance in a straight or curved line, and then again bent round, so that at the final turn the last elbow appears disconnected with the spire.

The shell of the genus *Ancyloceras* begins with a regular spire, the whorls of which are not in contact, as in the Scaphites, but are finally continued, as in them, for some distance in a straight line, and terminated by an elbow or cross. It commences with the lower oolites, and ends in the lower greensand,—not having been as yet discovered in the intermediate strata.

Ptychoceras : shell not spiral, but resembling a round or compressed siphon or tube bent back upon itself, so that the last turn is close to and connected with the first, appearing therefore, in a young state, as if straight. The septa are symmetrical, regularly divided into six slightly unequal lobes. The genus is confined to the lower greensand.

Baculites are straight Ammonites, the shell being either regularly conical, slightly compressed, or angular, like a straight horn, the upper portion being for a considerable space without septa, and the mouth furnished with a dorsal projection or beak, like some Ammonites. The septa are more simple than in the Ammonites, having only four lobes. The Baculites are peculiar to the Chalk period, which they therefore characterize.

Turrilites. In these chambered shells the spire is obliquely whorled, so that it resembles an ordinary turbinated univalve shell. The whorls are either round or

angular, and contiguous. The whole spire is umbilicated. This genus commences in the upper gault, and only extends to the upper greensand.

Helicoceras (D'Orb.). The shell resembles that of the Turrilites, but has its whorls disconnected. The genus has only been discovered in the gault.

In respect to other classes our remarks will be but brief.

The *Pteropoda* appear first in the Silurian epoch (Carboniferous period of Bronn), and then vanish to reappear in the Lias. They have not been hitherto found from that epoch upwards till the Tertiary period.

Gasteropoda. Of this great class the well-known recent genus Turritella appears first in the Cretaceous period, increasing in number of species through it and the Tertiary, up to the existing. D'Orbigny has described fourteen cretaceous species.

Scaloria: another well-known species, first commencing in this period, to which it has furnished seven species.

Rissoa. D'Orbigny describes one species of this genus, now common in all latitudes, obtained from the gault.

Rissoina,—a sub-genus; one species also from the gault.

Nerinea. This remarkable genus, which commenced in the Oolitic period, yields twenty-six species to the Cretaceous, and then disappears for ever.

Pyramidella. The greensand yields the first species of this well-known genus; the only species of the Cretaceous period.

Actæon (Tornatella of Lamarck): commenced in the Oolites, yielded ten species to the Chalk, and continued through the Tertiaries to the existing epoch.

Globiconcha (D'Orb.): a very globular, nearly spherical shell, with very short and almost concave spire. Peculiar to the upper greensand section of the Cretaceous formation.

Trochus. This genus, so common amongst living shells, was also abundant in the Cretaceous period, to which it yielded thirteen species.

Rotella. This living genus yielded its first species to the Chalk.

Stomatia. A living genus, in hot climates, which produced its only known fossil species in the Cretaceous epoch.

Pterodonta, distinguished from Pterocera by an internal tooth at the mouth, and by the want of a sinus, is peculiar to the upper greensand of the Cretaceous epoch.

The well-known genera *Conus* and *Voluta* existed in the Cretaceous epoch; the former having furnished to it one and the latter six species.

The genera *Mitra* and *Fusus* commence with the Chalk, the latter exhibiting seventeen species.

Colombellina (D'Orb.), confounded with *Rostellaria,* is peculiar to the Cretaceous period.

The common genus *Cerithium* commenced in the Oolitic and its species became abundant in the Chalk, numbering, in several sections, thirty-six.

Several other well-known genera either appear for the first time in the Chalk or are more fully developed in species than in preceding formations.

The total number of *Gasteropoda* described by D'Orbigny is 325, and he finds the number of species greatly increased in the upper geological divisions, being the inverse of the proportion observable in the Cephalopoda; so that we may assume, that whilst the peculiar forms of ancient faunæ diminish in number from the base to the summit of the Cretaceous epoch in the class of Cephalopoda, the peculiar forms of our recent fauna in other classes increase.

M. D'Orbigny draws some highly important geological conclusions from his examination of so great a number of Gasteropoda, which strongly mark the great importance of Palæontology.

1. There are distinct lines of demarcation between the successive faunæ of the earth, since up to the present time no evidence has been obtained of the passage of any one species of Gasteropoda from the Oolitic into the Cretaceous epoch, or of that of a Cretaceous species into the Tertiary.

2. At each great geological epoch there existed not only distinct species, but also genera and zoological forms peculiar to it.

3. No transition being observed in the specific forms from one formation to another, it may be assumed that the succession of organized beings on the surface of the earth was not by gradual passage, but by the extinction of existing races, and the creation of new species at each geological epoch.

4. These conclusions, drawn from the Gasteropoda, confirming in every respect those which have been obtained from the Cephalopoda, it appears that two distinct sets of Molluscs, the one, the Cephalopoda, the inhabitants of deep seas, and the other, the Gasteropoda, the inhabitants of the more shallow water of the sea coast, have combined to testify that the earth has been again and again depopulated, and again renewed in its living creatures.

These were the opinions of the great naturalist, D'Orbigny, who is now no more; but it must be observed that if the change or variation of the one form of a species into another were supposed to be determined by definite laws of periodicity, the same effect would be produced, as by successive acts of creation.

The great laws which have been thus traced in the progressive distribution of organic bodies, from the consideration of the Cephalopoda and Gasteropoda, are confirmed by the next great class, the *Lamellibranchiata.* These are the headless Molluscs which inhabit bivalve shells. Not possessed of the means of rapid movement like the Cephalopoda, or of crawling on the surface like the Gasteropoda, they are, for the most part, nearly sedentary in their habits, and consequently are the more liable to be limited in their extension, as they are the less able to remove themselves from injurious influences. D'Orbigny has described 553 species in the Cretaceous fauna, but we shall only quote from him a few of the genera which either connect generically the Cretaceous with the Oolitic period, or which, first appearing in the Chalk, are still members of the existing fauna, or which are peculiar to the Chalk.

Opis. This genus, though possessing a general resemblance to the genus Cardium (or Cockle), is very strongly distinguished by its very large and prominent beaks. It is peculiar to the Oolitic and Cretaceous periods, being most abundant in species in the former, though it has supplied to the latter six species.

Crassatella. A living genus in hot climates. The inhabitants of sandy shores, they bury themselves vertically in the sand. They commence with the Cretaceous period.

Cardita, Cyprina, and *Lucina* are considered by D'Orbigny to commence with the Chalk.

Trigonia. This genus, so strongly marked, and so characteristic of the Oolitic period (although one species is assigned by D'Orbigny to an earlier), abounds in the Cretaceous, producing there 21 species; yields only one to the Tertiary, and then in the recent period forms part of the extraordinary fauna of Australia,—a history which suggests to the mind many interesting speculations.

Myoconcha—peculiar to the Oolitic and Cretaceous periods.

Clavagella. This very remarkable recent genus yields its first species to the Chalk.

Leguminaria—a genus which gives very few species to the recent fauna, and gave its only fossil one to the Chalk.

Fistulana—first appears with the Chalk.

Lavignon (*Lutraria* of Lamarck)—begins in the Cretaceous period.

Arcopagia (separated from Tellina)—first occurs in the Chalk.

Thetis—peculiar to the Chalk.

Gervilia—common to the Oolitic and Cretaceous periods, and then ceases to exist.

Inoceramus—abundant in species, and ends in the Chalk.

Janira—a genus now separated from Pecten, &c., containing the formerly so-called P. quinquecostatus, P. quadricostatus, &c., begins in the Cretaceous period, is traceable in the Tertiary, and still exists.

Spondylus—begins in the Chalk.

Ostrea. This well-known genus of our present seas was early represented with the ancient faunæ under very distinctive forms: to the Chalk it yielded many species, some of which were very remarkable from the complicated manner in which the shell was folded or plaited.

Brachiopoda. The animals of this great class, which appeared with the very first of organic beings in the most ancient known fauna of the earth, the Silurian, are less perfect in their organization than those of preceding classes. They have no head, have neither organs of vision nor of hearing, and are deprived of all organs of motion. Whether free or attached, the species cannot change their place, and must therefore be peculiarly sensitive of great cosmical changes. It is thus that they have become powerful means of distinguishing formations or epochs, as may be judged from the following statement of the range of the several genera, in which it will appear that some of them are even more limited than in the other classes.

Lingula, from the Silurian up to the recent epoch, where it still exists.

Productus—*Chonetes*—*Leptagonia*—*Leptæna*—from the Silurian to the Triasic inclusive; and then disappear.

Orthis—*Orthisina*—*Strephomena*—*Hemithiris*—*Strigocephalus*—*Porambonites*—*Rhynchonella*,—of these only Rhynchonella is continued to the Chalk, where it ceases.

The eight genera constituting the families *Uncitidæ* and *Spiriferidæ*—not continued to the Chalk.

Magas is peculiar to the Chalk, and *Terebratulina* commences with it.

Of the family of *Terebratulidæ*, as restricted by D'Orbigny, the genus *Terebratula* is common to all geological formations, and is still living, whilst *Terebratella*, *Terebrirostra*, and *Fissirostra* are peculiar to the Chalk.

And of the second division of Brachiopoda, *Megathiris* and *Thecidea* appear in the Chalk, and are still living, the latter being attached to Coral at great depths.

Of the family of *Caprinidæ*, the remarkable genera *Hippurites*, *Caprina*, *Caprinula*, and *Caprinella* are all peculiar to the Chalk, and would, even taken alone, stamp an air of peculiarity on its fauna.

In like manner, the curious genera *Radiolides*, *Biradiolides*, *Caprotina*, and *Requienia*, which constituted the family of *Radiolidæ* of D'Orbigny, distinguished the Cretaceous fauna, in which, at several successive stages, their several species were grouped together,—forming in deep water extensive reefs, like the coral reefs of our present seas.

These great truths are equally manifest, if the inquiry be extended to the *Echinodermata*, and specially to the *Echinidæ*, as in the numerous genera and species of the Cretaceous epoch will be found some approximating to our recent types, but many (see Geology Plate XIII,) peculiar to the Chalk. The *Crinoidæ*, which, like the cephalopodous Molluscs of the tetrabranchiate order, commenced with the earliest epochs, have now almost disappeared; but the Echinidæ still maintain their importance in

numbers. The fauna of the Chalk, therefore, by turns approaches to or recedes from the ancient faunæ, on the one hand, and the existing fauna on the other; but though even a slight specific connection with the recent has been lately supposed to exist, it presents a bold aspect of difference, which, like a precipice, divides it from our own epoch.

Tertiary Period—(*s, t, u, v, w, x* of Table), or excluding *x*, and merging the local distinctions into the great leading divisions,—the Eocene, Miocene, and Pliocene of British writers; the Quaternary or Pleistocene embracing the still more recent deposits.

Before discussing the flora and fauna of this period, it will be well to refer to Table III., and to consider the proportion of fossil to recent genera in the successive formations, as the evidence of distinct systems is stronger when thus obtained from the greater groups of organized beings than from simple species. The genera may reasonably be expected to be less affected by the comparative areas examined than the species; or, in other words, it is more difficult to account for the total absence of many living genera from the fossil faunæ, and of the similar absence of many fossil genera from the recent fauna, on the mere supposition that it is due to the comparatively small fossil area examined. That reason is legitimate, and has great force, when it is applied to the question of comparative abundance of species, but it cannot account for the want of identity either of species or genera: and if the fact of a want of such identity is remarkable when derived form the smaller groups or species, how much more striking must it be, if found equally deducible from the greater groups or genera! Looking first to the flora, it appears that in the whole series of strata deposited from the earliest Silurian to the Cretaceous inclusive, no recent or now living genus of plants has as yet been discovered: whereas in the Tertiary one-third of the genera are still living.

The proportions of living genera of animals in the successive faunæ are given as follows:

	Carboniferous.	Trias.	Oolitic.	Cretaceous.	Tertiary.
In the *Phytozoa*,	$\frac{1}{4}$	$\frac{1}{2}$	$+\frac{1}{2}$	$\frac{3}{5}$	$\frac{3}{4}$
,, *Malacozoa*,	$\frac{1}{2}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{9}{10}$
,, *Entomozoa*,	$+\frac{1}{10}$	$\frac{1}{10}$	$\frac{1}{2}$	$+\frac{3}{5}$	$\frac{3}{4}$
,, *Fishes*,	0	0	$\frac{1}{10}$	$\frac{1}{4}$	$+\frac{1}{2}$
,, *Reptiles*,	0	0	$+\frac{1}{10}$	$\frac{2}{10}$	$\frac{3}{4}$
,, *Birds*,	0	0	0	0	$\frac{9}{10}$
,, *Mammals*,	0	0	0	0	$\frac{1}{2}$

An examination of these numbers at once points out the enormous zoological difference between the latest of the Secondary formations and the first of the Tertiary, —between, as it were, the more ancient epochs and that in which the world was almost prepared for the reception of Man and the organic beings associated with him.

The most striking fact in the Eocene or earlier division of the Tertiaries is the occurrence of Quadrumana. These remarkable animals, the next in order of organization to Man, were first recorded as inhabitants of the earth during the Tertiary epoch by Lieutenants Baker and Durand of the Indian army, in 1836, and again in 1837, by Capt. Cautley and Dr. Falconer; but in these cases the fossil remains were from a region the present climate of which is suitable to the existence of such animals. In 1837, M. Lartet discovered in the fresh-water Tertiaries of the South of France quadrumanous remains, and in like manner they have been discovered in the Tertiaries of South America; so that their appearance has thus been carried back to the very dawn of our present fauna. Professor Owen has remarked, that whilst "the fossil

Semnopithecus of India, and Protopithecus, or Capuchin Monkey of Brazil, are, like the lower organized extinct mammals associated with them, of gigantic size as compared with the nearest existing analogues of the same localities, it is interesting to find that the representatives of the quadrumanous order found in a climate which is now unfit for the existence of apes and monkeys in a state of nature, were of smaller size than their now nearest analogues; a fact which seems to indicate that although the climate was warmer than at present, it was not of so strictly tropical a character as to favour the full development of the quadrumanous type."

In the Eocene gypsum of Montmartre, Cuvier discovered the remains of Bats, and their existence in the Eocene sands has been rendered very probable. Such remains are also found in the Bone Caves, associated with extinct animals. In the most recent (or rather post-tertiary) beds of the Tertiary epoch, remains of the Mole, the Shrew, &c., have been found,—every step bringing us nearer and nearer to the ordinary condition of the existing fauna.

The necessary limits of this article will only permit a rapid sketch of the other peculiarities of the Tertiary fauna. The Chæropotamus of the Eocene strata is a link between the Hippopotamus and the Hog: it resembled the Peccari of Mexico, but was about one-third larger. The genus Hippopotamus occurs in the Pliocene fauna (H. major or great fossil Hippopotamus), and is represented in the Tertiaries of India by its congener, Hexaprotodon of Cautley and Falconer. Of other Pachydermata, the genera Hyracotherium, Palæotherium, Anoplotherium, &c., occur in the earlier Tertiaries, and mark them with a peculiarity which diminishes in the more recent, until at length both the genera and species are nearly identical with those of the living fauna. Of the above animals it has been justly remarked by Owen as a curious fact, that the nearest living analogues of the Chæropotamus, the Anoplotherium and Palæotherium, namely, the Peccari or Mexican Hog, the Llama, and the Tapir, should all be found in South America; so that the grouping of the British fauna in the Eocene epoch corresponded with that of the living South American fauna,—a fact which will remind the reader of a similar grouping of the Oolitic fauna as compared with that of Australia.

Turning to the Reptiles,—the Eocene epoch was rich in Chelonians, the London clay of our own island having yielded no less than eleven species of the marine genus Chelone, or Turtle. How striking is this fact, when it is recollected that only five well-defined species of Chelone have as yet been discovered, notwithstanding the eager search for these animals, by naturalists and commercial voyagers, in the tropical seas of our world! Fresh-water Tortoises are still represented in the European fauna by the Emys or Cistudo Europæa, which can live in our own island in suitable localities; but this extraordinary abundance of marine Chelonians in the Eocene fauna of England,—the Island of Sheppey alone producing more species of Turtles than are now known to exist in the whole world,—can only be explained by some great cosmical change. They agree with other organic bodies of the period in demonstrating a warmer climate to have prevailed during that period, and the production, under its influence, of an abundant supply of food. But, in addition to this, Professor Owen advances the truly philosophical opinion, that to some of the extinct species, which, like Chelone longiceps and C. planimentum, have a form of head well adapted for penetrating the soil, was assigned the task of checking the undue increase of the now extinct Crocodiles and Gavials of the same epoch, by devouring their eggs or young; just as in like manner they may have been in return an occasional prey to the older individuals of the same carnivorous Saurians. In the fluviatile Chelonians the same remarkable distinction of the Eocene fauna is preserved.

Of the genus Trionyx, or of the soft Tortoises generally, no species have yet been

observed in European rivers, "all those which have been described, and of which the habitat is known, having come from the streams, rivers, or great fresh-water lakes of the warmer regions of the globe;" but at the Eocene epoch the Trionyces abounded in the fresh waters of our latitudes, Professor Owen having described eight species.

Of Marsh Tortoises the numbers were not so great, comparatively speaking, since in the existing fauna this family exhibits the greatest number of species. Two species of the genus Platemys and six of the genus Emys have, however, been described by Bell and Owen; M. Pictot has lately added many new species of Chelonians discovered in the Tertiary deposits of Switzerland, and if the total number of Chelonians disinterred from Tertiary strata be considered, we shall be equally justified in designating the Tertiary as an age of Chelonians as we were in calling the Lias an age of Saurians.

Before turning from the contemplation of a fauna which at once embraced so great a variety of Chelonians, Serpents of very large size, great Lizards, and mighty Crocodiles, it is desirable to dwell for a moment on the reflections which they have excited in the mind of Professor Owen:

"The fossil reptiles," he observes, "like the fossil fishes, approximate nearest to existing species in the Tertiary deposits, and differ from them most widely in strata whose antiquity is highest.

"Not a single species of fossil reptile now lives on the present surface of the globe.

"The characters of modern genera cannot be applied to any species of fossil reptile in strata lower than the Tertiary formations.

"No reptile, with vertebræ articulated like those of existing species, has been discovered below the Chalk.

"Some doubt may be entertained as to whether the Icthyosaurus communis did not leave its remains in both Oolitic and Cretaceous formations; but with this exception, no single species of fossil reptile has yet been found that is common to *any two great geological formations.*

"The evidence acquired by the researches which I have detailed permits of no other conclusion, than that the different species of reptiles were suddenly introduced upon the earth's surface, although it demonstrates a certain systematic regularity in the order of their appearance. Upon the whole, they make a progressive approach to the organization of the existing species, yet not by an uninterrupted succession of approximating steps. Neither is the progression *one of ascent;* for the reptiles have not begun by the perennibranchiate type of organization, by which, at the present day, they most closely *approach fishes;* nor have they terminated at the opposite extreme, viz. at the Dinosaurian order, where we know that the reptilian structure made the nearest *approach to mammals.* Thus, though a general progression may be discerned, the interruptions and faults, to use a geological phrase, negative the notion that the progression has been the result of self-developing energies adequate to a transmutation of specific characters; but on the contrary, support the conclusion, that the modifications of osteological structure which characterize the extinct reptiles were originally impressed upon them at their creation, and have been neither derived from improvement of a lower, nor lost by a progressive development into a higher."

Cephalopodous Molluscs.—In the faunæ of preceding epochs the Cephalopoda have occupied a very prominent position, and have aided materially in characterizing them by the marked and highly important alterations of their structure, which became apparent in successive epochs. The family of Nautilidæ exhibited a great variety of modifications at the earliest fossiliferous epoch, namely, the Silurian; whilst the family of Ammonidæ preserved its primæval plan of structure nearly to the Cretaceous

epoch, when it assumed all those remarkable forms which have been described under the genera Turrilites, Helicoceras, Toxoceras, Hamites, Scaphites, Baculites, &c., &c.; so that the age of great development of the one family was at the earliest period of the Protozoic formations, and that of the development of the other family at the latest period of the Deuterozoic,—a fact which is strongly in opposition to the theory of progressive development. How remarkable, also, it appears, that after each of these epochs of extraordinary development of forms, the family which was the subject of it should have either relapsed into simplicity or entirely disappeared! most of the abnormal forms of the Nautilidæ, such as the Phragmoceras, Lituitus, Gomphoceras, &c., having vanished with the strata in which they first appeared, just as the similar abnormal forms of Ammonidæ vanished with the Cretaceous, or in the epoch of their birth. The sudden disappearance of the whole family of the Ammonidæ is one of the most remarkable facts of natural history, more especially as it is contrasted with the continued existence of the Nautilidæ, in its simple or normal form, both in the Tertiary and still existing epochs.

But before noticing the Eocene species, let us for a moment turn to the dibranchiate Cephalopoda, and mark the state of their development at this epoch. In the genera Belosepia, Beloptera, and Belemnosis are found connecting links between the Belemnites, which were such interesting members of the Oolitic and Cretaceous faunæ, and the Sepidæ, or Cuttle-fish, of the recent; and these three genera yielded six species to the British fauna. In these forms, therefore, the peculiarities of the more ancient dibranchiate Cephalopoda are disappearing, whilst the characters of the recent are becoming more distinct; but in this, as in the case of reptiles, the change cannot be said to be from the simple to the compound, but rather from the compound to the simple. In like manner, the most simple forms of the tetrabranchiate Cephalopoda have alone been preserved to our recent fauna. The genus Nautilus of Eastern Seas, first made known early in the last century by Rumphius, and first described with accuracy by Professor Owen, was indigenous to our British Seas in the Eocene epoch, having then contributed six species to the fauna of England. These deserve some special notice, in order to explain their supposed distinction from the recent species.

Nautilus centralis is small, those found not having exceeded 3″·7 in diameter; and in the simplicity of the septa and the central position of the siphuncle they nearly resemble the recent Nautili, whilst they are distinguished from them by a very ventricose and almost globose aspect, the dimensions of the largest specimen being 3″·7 in diameter and 3″·3 across. It is probable that this species extends into the Miocene strata.

Nautilus regalis—a very splendid species, as it has been known to attain the size of 9½ inches in diameter and 5 inches across. The umbilicus is closed by a thickening of the lip, which looks like a solid axis to the shell: the siphuncle is small and eccentric; the septa are nearly simple, presenting on each side slight undulations. In the young shell the septum is characterized by a conical depression placed on the dorsal margin, close to the preceding whorl, and having the appearance of a second siphuncle, for which it has been mistaken.

Nautilus urbanus—a flat discoidal shell, with obscure undulations like those of N. regalis. The siphuncle is eccentric, approaching the dorsal margin; the umbilicus is narrow, but open. It is distinguished from N. centralis by its flatness and the greater length of its aperture, and from N. regalis by its open umbilicus and discoidal shape. It attains a large size, namely, 7″·4 in diameter and 3″·4 across.

Nautilus imperialis.—This species is easily distinguished from N. centralis by an eccentric position of the siphuncle, and from N. regalis and N. urbanus by its orbicular form, lunate septa, and recurved dorsal lobes, which form, as it were,

an axis to the shell; a very large species having attained the size of 12 inches by $8\frac{3}{4}$ across.

Nautilus Sowerbyi—a discoidal, or rather a lenticular shell, the aperture having a triangular aspect. The septa are very concave, having on each side a broad undulation with a deep sinus-like depression, caused by a lateral lobe: the siphuncle is very near to the dorsal margin. It has attained the size of 10 inches diameter by 4''·2 across.

Nautilus Parkinsoni.—The septa are moderately concave, with angular lobes on each side. In this latter respect it resembles Aturia zic-zac, whilst it possesses the siphuncle of the genus Nautilus, which, though very eccentric in this species, is still truly discal. It is a connecting link between the Nautili and Clymenidæ, and through the latter leads to the Goniatites and Ammonites. It attains a very large size; the largest chamber in Parkinson's specimen, and that chamber manifestly not the last, measuring 9 inches by 7.

From these descriptions it is manifest that the genus Nautilus was still in a highly developed state in the Eocene formation: it continued so in the Miocene, and it still exists, though now diminished in size and number of species, and confined to the seas of the tropics. It is, therefore, a connecting link between the extinct and the recent faunæ.

Of the family of *Clymenidæ*, of which the genus Clymenia (Munster) is the type, there is also a representative in the Tertiary, though none in the recent epoch. In the description of D'Orbigny's classification, it was stated that Clymenia or Aganides (D'Orbigny having adopted the name given by De Montfort to a species which is now supposed to be a Goniatite), having flourished as a characteristic genus in the Protozoic formations, suddenly disappeared, to reappear, as it were, for a moment in the Tertiary. Bronn, however, has established a separate genus for the Tertiary shells, under the name of Aturia, as the whorls are exposed and the siphuncle is narrow in Clymenia, whereas in Aturia the last whorl conceals the others, and the siphuncle in the typical species, Aturia zic-zac, is of great size and funnel-shaped, though in both there is the same position, namely dorsal and marginal, of siphuncle. These differences, following the analogies of classification in the genera Nautilus and Ammonites, scarcely justify generic separation, unless indeed they had been manifested in a number of species of the new genus Aturia.

The *Aturia zic-zac* (Nautilus zic-zac of Sowerby) was very widely distributed, having occurred in the Eocene strata of Europe and America, and been continued into the Miocene. The zic-zac or pointed character of the lateral lobes of the septa, and the trumpet-shaped siphuncle at present distinguish it as a species.

The nature of the differences between these species merits careful consideration in a philosophical point of view, as it cannot be considered of an order likely to affect materially internal organization, though still sufficient to serve as geological records in distinguishing between successive formations.

It is unnecessary to pursue this investigation into the other classes of Mollusca which exhibit the continued approximation in genera and species to the recent fauna of the earth, as we have now arrived at that point where the ancient is blended into the modern world. In pursuing our course through this interesting enquiry, we have mostly selected examples from European data, as they were best calculated to exhibit to us the peculiarities of successive faunæ in contrast with that now existing; but had our object been to refer to extinct animals as a necessary portion of the studies of a Zoologist, many very curious examples might have been cited from South Africa and the East Indies.

Even still later in the World's history, the mighty Mastodon and the extinct

Elephant, Bear, Rhinoceros, Hippopotamus, Giant Deer, &c., still marked a distinction in the fauna; but as species of most familiar kind were associated with them, such as the Fox, Wolf, Badger, Otter, &c., it is difficult not to consider them portions of the present system; nor indeed is there so great a difference between some of them and existing species as there is between the now extinct Dodo and Solitaire of the Mauritius and Isle of Bourbon, and more common genera and species of those and other localities. In these later deposits, however, may still be noticed the remarkable occurrence of forms now only known in warmer latitudes; and it would appear, therefore, that they had gradually died out of the Northern faunæ, though represented by closely allied species in the Southern. The mode in which these great changes have been effected must ever continue to us a mystery, but the fact remains an important guide in geological speculations.

Distribution of Species.—The distribution of marine animals, which form so large a proportion of those which have preserved to us a knowledge of the more ancient faunæ of the earth, must necessarily deserve attentive study; and for this purpose we cannot do better than examine the principles established by Professor Forbes as the result of his dredging inquiries. He states that the distribution of marine animals is determined by three great primary influences, namely,—climate, composition of the sea bottom, and depth,—corresponding in character with those which determine the distribution of land animals, namely,—climate, mineral structure, and elevation,—these primary influences being modified by several secondary or local causes.

In the Eastern Mediterranean, eight well-marked regions of depth were characterized each by its peculiar fauna, and wherever plants were present, by its flora. These organic assemblages include some species which are only found in one particular zone, some which existed in preceding but do not continue into subsequent zones, and some which, beginning in that zone, continue to exist in succeeding zones.

In this manner certain species have their maximum of development in one zone, and being there most prolific in individuals, may be regarded as especially characteristic. The sea bottom, in its mineral character, has generally a certain uniformity in each zone, that uniformity being more decided in the lower than in the upper zones. The deeper zones are greater in extent, so that whilst the first or most superficial is but 12 feet, the eighth or lowest is above 700 feet in perpendicular range; and the more purely littoral animals were therefore more subject to limitation than those of deep waters: it is by the careful study of the results of the laws which have regulated the distribution in depth of living marine organisms, that it becomes possible to deduce the former living position of fossil organic relics.

First Region, or Littoral Zone.—This is the least extensive, as two fathoms may be considered its inferior limit, and its mineral nature is as various as the coast line; but limited as it is, there are well-marked subdivisions. The variety of its bottom necessarily produces, according as it is sand, rock, or mud, a variation in the association of its several species. That portion which, forming the water-mark, is left exposed to the air during the ebb of the tide, presents species peculiar to itself, which resist the effect of so great a change, by either closing their valves or burying themselves in the mud or sand. In the lower portion of this zone are the most characteristic species, the colours both of shells and animals being most fully and beautifully developed. As local influences, such as variation of sea bottom, differences in tides and currents, flowing-in of rivers, &c., now induce a peculiar or local distribution of species, the same effects must have been produced from similar causes in the ancient faunæ. The fauna of this belt must be also varied by many stray species,

either driven in by storms or brought down by rivers, land shells and plants being frequently mixed up with its true marine inhabitants.

Professor Forbes enumerates from the Ægean Sea 38 species of the Lamellibranchiata and 107 of the Gasteropoda.

Second Region.—It extends from 2 to 10 fathoms, and the sea bottom is generally either sand or mud. In the Mediterranean, the Holothuriæ abound in this region, as do the burying Conchiferæ.

In the Ægean this zone produced 34 species of Lamellibranchiata, and of the Gasteropoda 76 species, so that the number of species is considerably less than in the preceding zone; and it may also be observed that not being entirely beyond the action of the storm wave, its inhabitants are often washed up and carried into the littoral zone.

Third Region.—From 10 to 20 fathoms, the sea bottom being generally gravelly in places, with great tracts of sand. This zone presents few peculiarities, and is, as it were, one of transition. Large Holothuriæ are still abundant,—of Lamellibranchiata there are 51 species in the Ægean, and of Gasteropoda 74. There is little doubt that the extension of the muddy sea bottom of the last zone into this, leads to an approximation in the zoological characters of the two zones.

Fourth Region.—From 20 to 35 fathoms. The sea bottom is very various, mud and gravel prevailing, sandy tracts being very rare. Sponges abound, some of the finest used in commerce growing here. Amongst Fuci, Codium bursa is quoted in this zone; it occurs, however, in the preceding in the channel of Corfu.

Of Lamellibranchiate species the Ægean yielded 67, of Gasteropoda 88; in respect to which some cautionary remarks are necessary. Dentalium rubescens, which occurs in the fourth zone, appears also in the first, but not in the second or third: such a distribution seems to imply a mere local result, as the depth of the fourth zone is such as to remove its species from any action but that of currents, and these must have passed the species over the intermediate zones, had they been thus disturbed and moved. Aporrhais pes-pelecani occurs highly developed in the third and fourth zones, but not in the second; but it is highly probable that in other localities it would be found in the second also. In this region the Brachiopoda first appear, yielding two species.

Fifth Region.—From 35 to 55 fathoms, presenting a well-marked fauna. The sea bottom is generally nullipore and shelly, mud being rare. Of Lamellibranchiata, in the Ægean, it produces 58 species,—of Gasteropoda 79, and of Brachiopoda 4.

Sixth Region.—From 55 to 79 fathoms, nullipore being the prevailing sea bottom. Fuci have become very scarce. Of Lamellibranchiate Mollusca 48 species, and of Gasteropoda 43 species, were observed in the Ægean, and of Brachiopoda 5. Pectunculus pilorus is given at its full development, and it occurred also in the fifth zone; but there can be little doubt that it exists also in much higher zones.

Seventh Region.—From 80 to 105 fathoms,—has a characteristic fauna, with a sea bottom generally of nullipore, and more rarely of sand or mud. Herbaceous Fuci have disappeared, as also Mollusca tunicata. Echynocyamus amongst the Echinida occurs frequently alive, but its range extends much higher, as it is not unfrequently found alive in the third region in the channel of Corfu.

The Lamellibranchiata yielded only 33 species, and the Gasteropoda 42; but the Brachiopoda were here increased to 7 species.

Eighth Region—includes all the space below 103 fathoms, and extends to the depth of 230 fathoms, having an uniform and well-characterized fauna, distinguished from all the preceding by species peculiar to itself. Within this region the number of

species and of individuals diminishes as the depth increases, pointing to a zero in the distribution of animal life not yet arrived at.

The Lamellibranchiata amounted to 30 species, the Gasteropoda to 23, and the Brachiopoda to 3. Of these, only 8 of the Lamellibranchiata were taken alive, and 3 of the Gasteropoda,—all the Brachiopoda and 10 Pteropoda, &c., in addition, being dead. Of the Gasteropoda, 17 species, with 23 Lamellibranchiata and 3 of Brachiopoda, occurred at depths between 140 and 180 fathoms; 4 Gasteropoda, 11 Lamellibranchiata, and 1 Brachiopode, between 180 and 200 fathoms; and only 1 Gasteropode, 4 Lamellibranchiata, and 1 Brachiopode, above 200 fathoms.

The zero of animal life is supposed by Professor Forbes to be about 300 fathoms, the sea bottom being mud without organic remains.

It is found on examining the species with reference to their occurrence in other countries, that those which appear to have existed in a greater number of zones yield a higher per-centage of Celtic or British forms than those which are confined to a smaller number of zones; for example, of those which are common to four or more zones, ⅓rd are Northern, whilst of those which range through less than four regions, only a little above ⅕th are common to the British seas. And from these facts this general law is deduced,—*That the extent of the range of a species in depth is correspondent with its geographical distribution.*

Professor Forbes gives the following Table to illustrate another important consideration in respect to the distribution of species; namely, its variation as regards the different families of Testacea.

Distribution of British Forms in the several Zones of the Ægean Sea.

FAMILIES.	I.	II.	III.	IV.	V.	VI.	VII.	VIII.
Multivalves	1	0	...	1	1	1	1	0
Patelliform univalves	0	1	2	2	2	2	2	0
Tubular univalves	1	1	0	0	0	0	0	0
Holostomatous spiral univalves .	12	9	13	16	14	11	8	4
Siphonostomatous spiral univalves	4	5	7	8	9	6	5	2
Testaceous Pteropoda and Nucleobranchiata	.	...	...	...	...	...	0	0
Brachiopoda	...	...	...	0	0	0	0	0
Conchifera and Lamellibranchiata.	16	25	28	39	33	19	11	7
Total . . .	34	41	50	66	59	39	27	13
Per-centage .	23	32	40	41	42	33	31	20

From this Table it appears that the least per-centage of the whole number of Testacea is found in the highest and lowest zones,—the greatest in the 3rd, 4th, 5th, and a medium per-centage in the 2nd, 6th, and 7th.

The cause of these results may be traced to the small range of some species, as may be observed on comparing the number of British forms in the preceding Table with the total numbers in the following.

Distribution of Ægean Shells in Depth.

FAMILIES.	Total.	I.	II.	III.	IV.	V.	VI.	VII.	VIII.
Multivalves	7	3	2	0	2	2	1	1	0
Patelliform univalves	20	11	3	2	3	5	6	6	1
Tubular univalves	6	4	4	2	2	1	1	2	2
Holostomatous spiral univalves .	115	50	40	40	44	35	28	17	15
Siphonostomatous do. do.. . .	104	40	27	30	41	36	30	16	5
Testaceous Pteropoda and Nucleo-branchiata	12	1	0	0	0	0	0	3	12
Brachiopoda	8	0	0	0	2	4	5	7	3
Conchifera and Lamellibranchiata .	135	38	53	52	68	58	48	34	28
	407	147	129	126	162	141	119	86	66

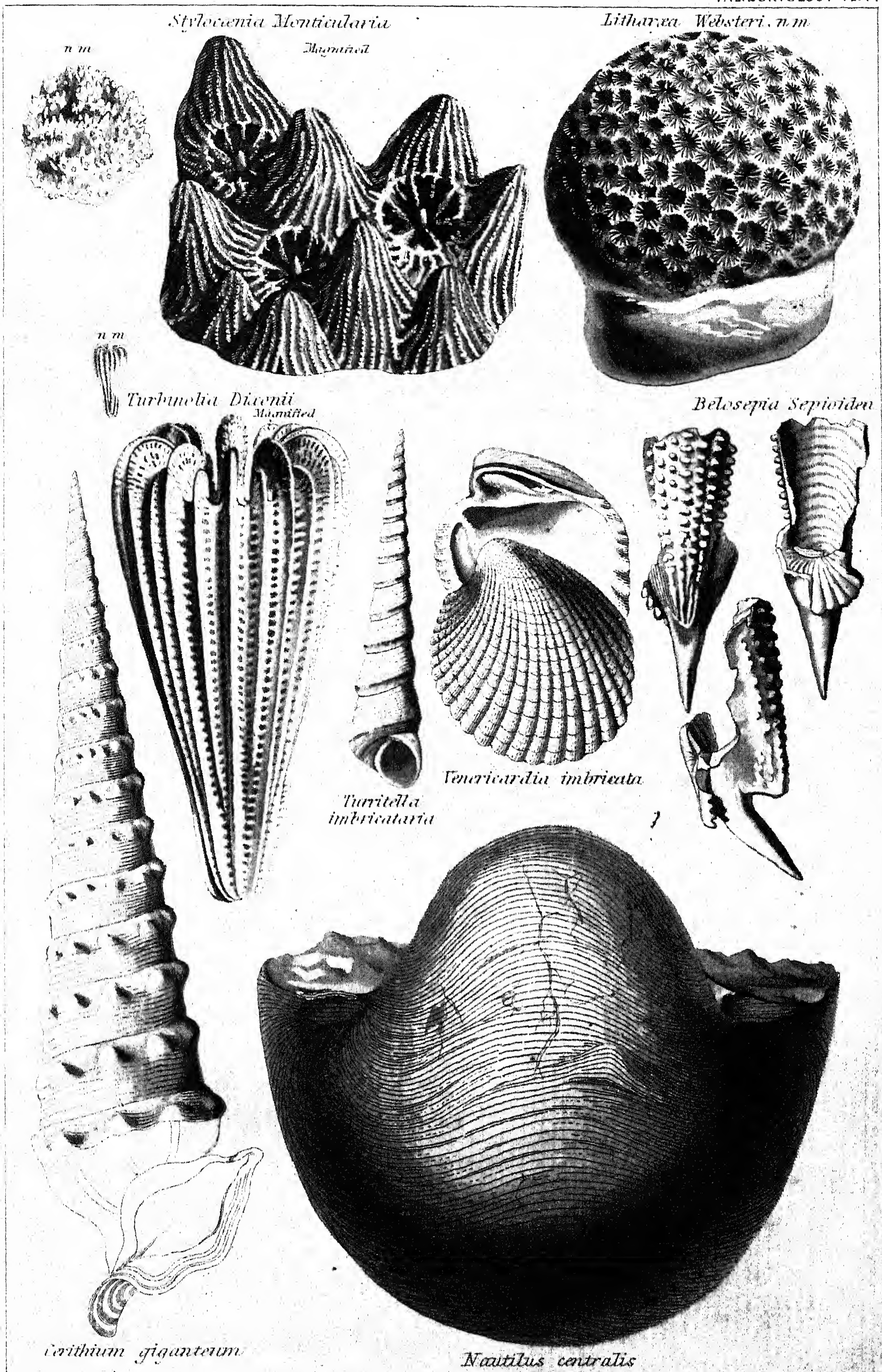
And it is evident, therefore, that the Geologist, in his reasonings on the fossil faunæ of past epochs, must take into consideration not only the total number of species, but also the number of species in each family, in order to arrive at safe conclusions as to climatal changes; and in doing so he must also bear in mind the great influence of the sea bottom in determining the presence of certain families of Testacea.

It will be readily believed that these zones of depth must be the scene of incessant change, as in one place the mineral matter is washed away, and in another it is deposited, increasing or decreasing the depth; and, in like manner, the same effects may be produced by the depression or elevation of the sea bottom from movements of disturbance, movements which are still continuing, and which were so powerfully exhibited in ancient epochs. In this manner the lateral distribution of a species is often arrested by a change of the sea bottom, and its total annihilation produced by a sudden alteration of the depth suited to its existence. When the change is only in depth, those species which have the power of existing through a great range will continue to live, whilst others will dwindle away and die; but when the change of depth is accompanied by a change of sea bottom, the effect will be at once a diminution in the number of species, and also a cessation of some of the families. Professor Forbes has also remarked that the long-continued and undisturbed existence of Testacea, on any ground, must, by the accumulation of their dead débris, render that ground unfit for the continuation of life until it has been covered with a new layer of sedimentary matter, uncharged with organic contents,—so that beds rich in organic remains may alternate with others containing none; a phenomenon well known to the Geologist. Every species has, according to Professor Forbes, three maxima of development,—in depth, in geographic space, in time. In depth, it is at first represented by few individuals, which become more and more numerous, until it has attained that precise zone where all circumstances most favour its growth, when it begins to diminish in number, and at length disappears. So, also, in geographical range, it multiplies until it has attained the climate most suitable to its growth; and in time, or geological range, a similar maximum may be observed; but in this case it should be premised that the continuance of a specific form ought generally to correspond with a geological formation.

Applying these reasonings to former epochs, the Geologist must bear in mind that there may have been then, as now, a beginning and minimum of development of particular species in some one section of a formation, an increase in its development, as it proceeded from the centre of creation, until it had attained its maximum, and then a gradual diminution to a second minimum. The modification or destruction, by whatever cause it may have been produced, of the fauna of a formation, was not

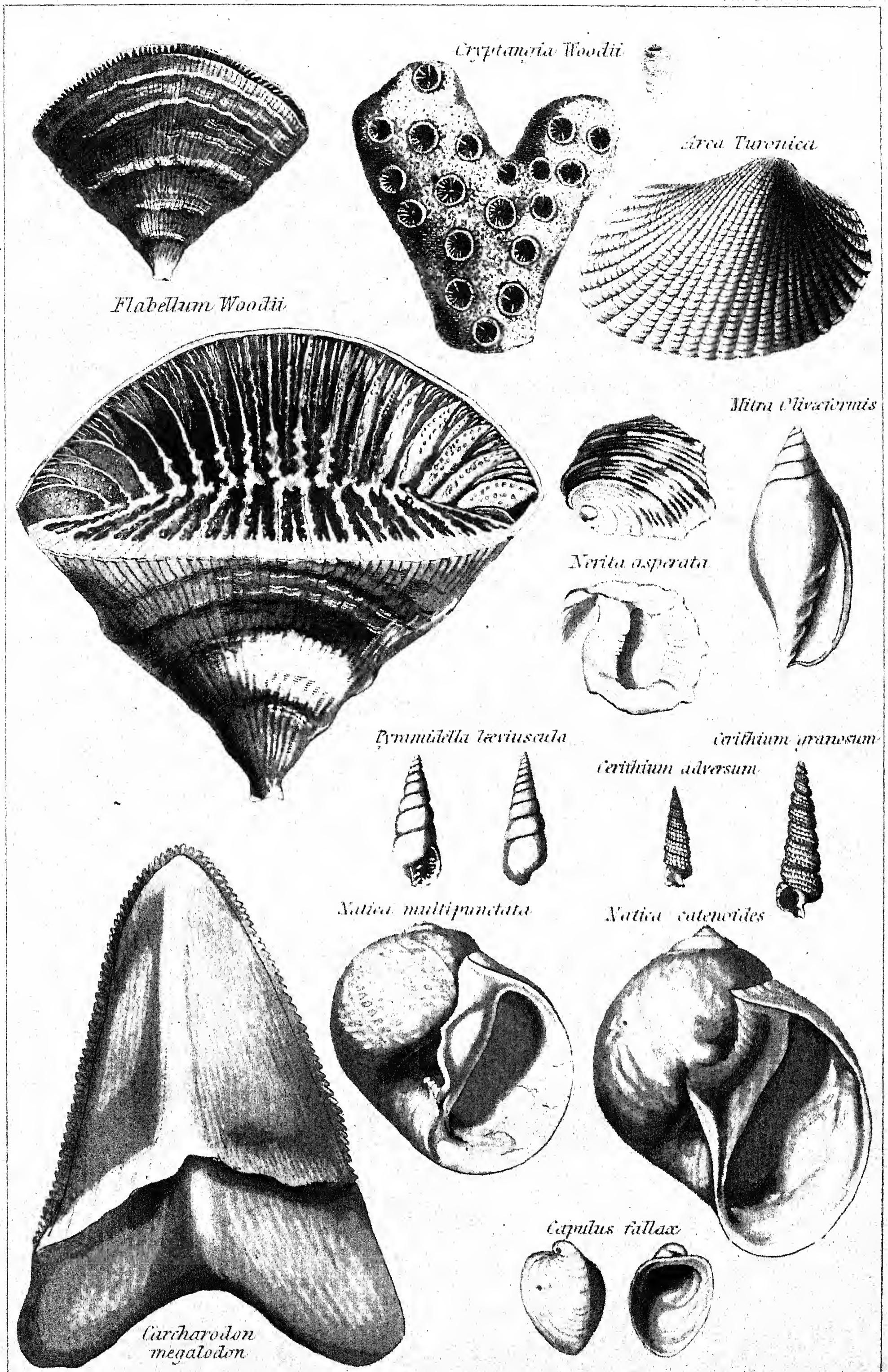
EOCENE FOSSILS.

PALÆONTOLOGY PL. I.



J. W. Lowry sc.

London, John Weale, 59, High Holborn, 1851.



J. W. Lowry fc.

London, John Weale, 59, High Holborn, 1851.

therefore always coincident with the duration of a species, but often took place when it was at its maximum of development, as is strikingly exhibited in the fauna of the Chalk, and has been pointed out in the remarks upon the various genera formed after the type of Ammonites, which, having attained a very high degree of development, were abruptly cut short, and ended with that formation. The study of the sea bottom, as manifested by the nature of the mineral deposits, and the classification of the genera and species according to the probable depth of their usual habitat, must necessarily precede any deductions as to the climate and position of the deposit. Nor must it be forgotten that the limits of the several zones of existence may in the faunæ of former epochs have been greatly modified by climate.

Palæontology, viewed as a branch of Zoology, has not only brought before the Geologist proofs of the existence of numerous forms of organic beings, which were associated together in groups, and which have since passed away,—but has also enabled him to reason with certainty, by reference to the natural characters and habits of extinct animals and plants, on the varying mineral conditions of each successive stage in the Earth's History. He is perhaps surprised at first to find how large a share organic beings have had, by their débris, in the formation of those stratified deposits which seem to the uninstructed only crude masses of mineral matter; but when he has discovered order and design in their structure and distribution, he traces in them the power and wisdom of the Creator, as manifested at successive epochs in peopling the world with beings suited to its actual state,—and, finally, he observes, that Man appeared just as every part was so nearly balanced that it was in the power of an intellectual being to maintain his position safely and securely; the recent discovery of flint weapons, fashioned by the hand of Man, either associated with the relics of long extinct animals, or in deposits below them, proves that this appearance took place certainly within the Tertiary epoch, though it does not afford sufficient data for determining the time of his creation.

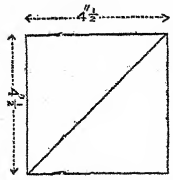
Palæontology has thus enabled the Geologist to discover from the abrupt disappearance of whole families of organic beings, even if he had not been aided by stratigraphical disturbances, the epochs of great cosmical revolutions, just as in the peculiar distribution of ancient animals it has given him a clue to the discovery of every feature of each successive phase of the earth: guided therefore by Palæontology, his eye is carried over the sea shore, the deep sea bottom, the coral reef, the estuaries of the oceans of ancient worlds, of which he becomes at once the Natural Historian and the Geographer.

PALISADES form one of the auxiliary means of defence in Permanent and Field Fortification: in the former they are usually planted in the covert-way, and in the latter in the ditch of a work. The palisade is a necessary security of the covert-way, and the covert-way an important part of permanent fortification, if the ditches are dry, to prevent surprises, and facilitate and support sorties. To fortresses, citadels, and large forts with wet ditches, it is questionable if the covert-way is necessary, and dispensing with the palisade is a great saving of expense, as wood is a perishable article, except to the *couvre-portes*, or works covering the entrances and bridges.

In respect to the palisading of the covert-way of permanent works with dry ditches, several writers, among whom is Carnot, propose to omit the covert-way in their construction, and to substitute the glacis *en contre-pente* (see page 47 of the second volume of this work), arising from the objections to the palisade, on account of the great cost, and its being liable to be destroyed by the enfilade batteries during a siege; but this part of the objection applies only to the fronts attacked, perhaps not more than

$\frac{1}{6}$th or $\frac{1}{7}$th of the whole enceinte. Carnot's intention was to discourage passive resistance, and afford the garrison of a place the means of turning the defensive into offensive war, which in very large fortresses is of great importance. However, where there is a covert-way, palisading becomes indispensable, and the palisade is usually fixed on the banquette, about one foot from the glacis, and standing about one foot above the crest. The palisade may consist of young trees, cleft in two, with the flat sides spiked into a riband placed at the height of the covert-way, so that the soldier can rest his musket upon it; or it may be of young trees: in either case, the lower end is planted firmly 3 or 4 feet in the ground, and the upper end connected by the riband of scantling or split timbers. When the timber runs large, it is better to construct the palisading of frame-work, sawn into lengths of about 8 feet and 8 inches square: these will serve for posts. Smaller scantling of $4\frac{1}{2}$ inches square, and 10 feet long, sawn diagonally, as explained in fig. 1, form the rails and palisades. (See figs. 2 and 3.) The palisading is formed into bays about 10 feet from centre to centre, with the two rails tenoned into the post.

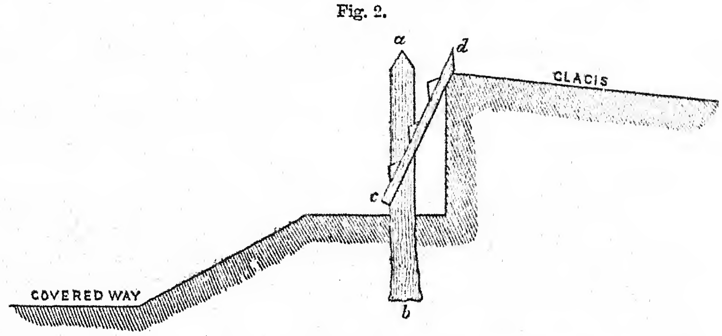
Fig. 1.



Oak and fir are best suited for palisading.

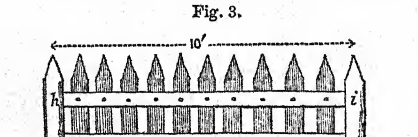
It has been proposed (see the 9th volume of Professional Papers) to frame the palisading in such a manner as will facilitate sorties, in a better manner than barrier gates, and protect better the troops returning into the covert-way. This may be done by placing one or more bays on a pivot or gudgeon fixed to the posts, and secured at top by a bolt, the gudgeon being on the bottom rail and the bolt upon the upper one.

Fig. 2.



The section of this construction is shewn in fig. 2, $a\ b$ being the post, and $c\ d$ the palisade, sloping back against the crest of the glacis; the ribands, of which an additional one is placed in the centre, serving as steps to mount upon the glacis. This contrivance is less expensive than the ordinary way of providing for sorties, and it does not diminish the security of the covert-way. The diagram (fig. 3) is the same in elevation, but the gate or barrier is closed, $f\ g$ being the gudgeons, and $h\ i$ the bolts for securing the gate when shut.

Fig. 3.



Palisading for field-works is seldom of timber sawn into scantling, but is constructed

of unhewn timber of trees suited to the purpose, planted firmly in the ground, and connected above with a riband, into which the palisades are spiked.

The position of the palisading for the security of field fortification should be under musketry fire from the parapet, or from some flanking work, to command the ditch within a caponière or gallery in the counterscarp; but these are seldom adapted to works of the moment. The positions shewn in figs. 53 and 54, Plates VII. and VIII. of Field Fortification, are best for the palisading of such works, so as to be seen from the crest of the parapet, and yet be partially secured from an enemy's artillery. The palisading should not be of less dimensions than 6 inches in diameter, and from 10 to 12 feet long, of which 4 should be fixed firmly in the ground.

Sir John Jones, in his 'Journals of Sieges,' note 25, observes—"The French planted admirable palisades in the ditches and rear of their works; each palisade was the rough stem of a young tree or the half of a larger one, fixed to a heavy beam four or five feet under ground. To cut through these palisades, in their usual confined situation, is a work of half an hour, and to force them impossible, so firmly are they planted; they are therefore an excellent defence when covered from cannon."

In the article 'Petard,' it will be seen that even this description of palisade is not secure unless protected by musketry fire.—G. G. L.

PARAPET. See Fortification, Field.

PASSAGE OF RIVERS.

PART I.—MILITARY OPERATIONS AND CONSTRUCTION OF TEMPORARY BRIDGES.*

1. This portion of the subject is intended as a sequel to the articles on Field Bridges given in the first volume: it has been obtained in fragments from various contributors, and is now embodied for the purpose of affording all the information attainable on so valuable a part of the duty of Military Men.

2. The passage of a river by troops or carriages, even when they are not in the presence of an enemy, is often difficult, and generally causes much delay in the march; therefore, as the success of a campaign, and security against disaster, often depend upon the rapidity with which a river can be crossed by an army, all the details connected with this operation should be well considered before it is attempted, so as to prevent unforeseen delay, and facilitate the calculation of the time required.

3. If the river to be crossed lie in the country occupied by an enemy, the best maps and correct information should be procured, and a careful examination made of that part which is likely to be the scene of operations,—noting the source and its mouth,—whether it flows to a sea, lake, or a large river,—the points where it ceases to be fordable and becomes navigable,—where it is joined by tributaries,—the nature of those tributaries,—the places where the river changes its direction,—the towns, villages, and houses on its banks; also the nature of the bed of the river; its extent during the flood and during droughts, with the cause of the variations; whether there are means of inundating the country, and whether there are any dikes, dams, or canals, and the effect if these are destroyed; the nature of the mouth of the river, if

* By Major Gibb, Royal Engineers.

there is a bar, and whether fordable and shifting. In the event of any immediate operation being contemplated, the effect of the tides and winds should be considered; if there are any islands and sand-banks, whether they obstruct or would facilitate a passage; and if the sand-banks are liable to shift;—the heights of the banks of rivers should be noted and sketched, if favourable for a passage, and information obtained as to the means of collecting boats or materials for the construction of a bridge or of rafts.

4. *The passage of a river in the presence of an enemy* presents many difficulties: the point where it is proposed to effect it must therefore, if possible, be concealed from the enemy. In the determination of this point, the object of the campaign must be considered, the advantages which, after the passage, the opposite bank gives for the construction of a temporary bridge, and the security which the ground will afford, by the aid of batteries or other field-works. The banks of the river should not be marshy, and they should be accessible for carriages.

5. In the selection of a point for the passage of a river by an army, the re-entering angle or bend may in some instances be found to afford many advantages, as the opposite bank is more easily defended, the current of the river is less rapid, and there is a greater depth of water for a bridge; and any island in the river gives facilities in crossing as well as in protecting the passage.

6. If the enemy is in force ready to defend the passage of an unfordable river, the operation becomes difficult, as the troops are liable to be cut off in detail as they cross. Most successful operations are secured by stratagem, that is, by deceiving the enemy as to the precise point intended to be crossed: this may be effected by commencing operations at a point which may be changed when it is dark, and crossing at another point which the enemy has left unopposed.

7. As regards the tactical part of this subject, the first operation is usually undertaken by detached means, supported by artillery, when troops are placed in row-boats, or on rafts, collected in the neighbourhood, and passed to the opposite side of the river as hastily as possible, where they secure themselves, taking advantage of localities to keep their ground until supported. When in sufficient strength, the troops should intrench themselves, and be reinforced by artillery. Fords* are sometimes available in the immediate vicinity of a point selected for the passage of an army, which may serve for cavalry and light artillery; but some caution is necessary in the presence of an enemy, as he may cross by the same means, and attack you in front and rear, whilst your force is separated by the river. The passage by swimming† will serve to assist in such operations, where the current is not rapid or the banks abrupt: the direction of the crossing should be with the stream, taking advantage of cross currents and eddies, and keeping clear of rocks. The infantry may convey their arms and ammunition on rafts, or on inflated skins, or pitchers securely connected; or they may take with them a rope supported by cork floats, or any other material inflated. The cavalry should take care, in swimming their horses across, to allow them perfect freedom of motion, the soldier keeping his legs back, holding steadily by the mane, and directing the horse with a light hand. If boats or rafts are used, the horses can swim astern, with their halters attached to them, in all cases taking care that they have plenty of room to avoid touching each other.

8. Before closing these slight preliminary theoretical notices on the passing of troops over rivers, the subject may be considered as strategetic or as a tactical operation. In the first case, the means adopted for passing a river must be of a substantial nature,

* See article 'Ford.' † See 'Swimming.'

and a certain degree of permanency must be secured, to stand the effects of the weather, and the probable floods of rivers which generally follow the wet season; and the security of the bridge or ferry against the enterprises of an enemy is also an essential consideration. Should the passage form one of the main roads for the supply of the army, or the line of retreat in case of any retrograde movements, great care must be taken to secure it from any possible disaster.* In the second case, considered as a mere tactical operation, the passage of a river will probably be for temporary purposes for the moment or for a few days, when the means required may be slight, and the celerity of the operation of the first importance, the defence of the passage becoming unnecessary. All well-organized armies are furnished with a bridge equipment to each corps, at least, with one for the advanced guard; but whether the passage is formed of materials obtained on the spot, or by a bridge equipment, they are usually removed after the passage is effected. Up to this date (1860) it does not appear that the means of passing rivers have been brought to perfection, nor are bridge equipments of a sufficiently portable nature to accompany corps and detachments in rapid movements in difficult countries. Field Bridges are still cumbersome, and a large establishment of men and horses is required to transport the equipment. In the British Service, in fact, there is no fixed establishment for effecting the passage of rivers.

9. *Rules for ascertaining the Width of a River; 1st, without Instruments.*

To ascertain the inaccessible distance A X (see fig. 1), measure any convenient length A C or A C′ in the prolongation of A X; and if the ground will admit of a line being laid down perpendicularly to the right or left of A, measure the triangles A B C or A B′ C′, making the sides in the following proportions; viz. A B = 4, A C = 3, and C B = 5, and prolong A B to any point D; then lay down D O in the same way perpendicularly to A D, and fix a mark at a point in it which is in the prolongation of B X.

Fig. 1.

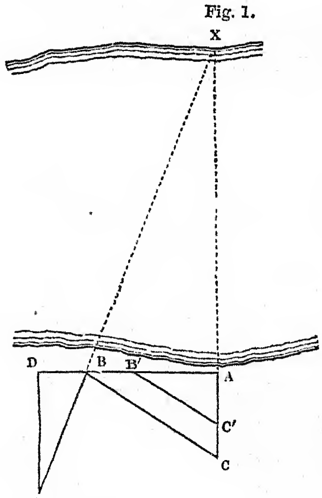


Fig. 3.

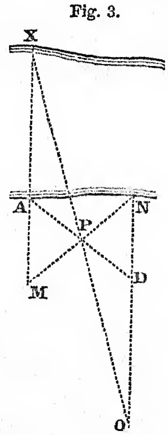
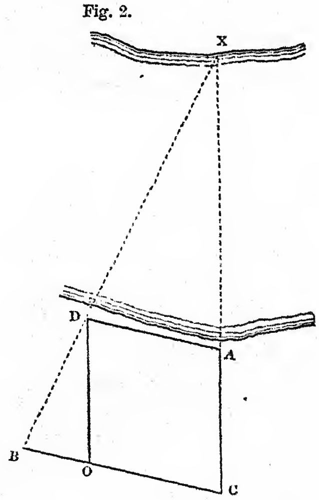


Fig. 2.



Then as B D : B A : : D O : A X.

Or (see fig. 2) measure A D in any convenient direction, and make O C equal to it,

* See 'Tête du Pont.'

also measuring D O equal to A C, and then fix a mark at B in the prolongation of D X and O C.

Then, as B O : D A :: D O : A X.*

2ndly, with a Sextant, Compass, or Theodolite.

The lines may be laid down as in fig. 1, taking care to make the angle B A X = B D O, and the calculations may be made as before; or measuring A B as a base, and ascertaining the angles X A B and X B A, the distance A X may be found by trigonometry.

10. *To find the weight which any floating body will support*, first calculate the number of cubic feet of water displaced by it, which for solid timber and air-tight cases may be considered equal to the entire bulk; but for open boats, which cannot be safely immersed lower than within 9 inches of their upper surfaces, the bulk below that level can only be calculated on. Multiply the number of cubic feet of water displaced by 1000 for fresh water, and by 1026 for salt water, which will give the weight in ounces: from this must be deducted the weight of the body itself with the superstructure, and the difference will give the weight which can be supported. The weight in ounces of the materials is found by calculating their cubic feet, and multiplying that by their specific gravity, which for oak is 950, for elm 670, and for male fir 580; but it must be remembered, that if timber be not tarred, its weight will be increased $\frac{1}{8}$th by imbibing water after being immersed two or three days. The weigh pressing upon a bridge during the passage of infantry four deep would be that of 20 men, or about 3600lbs., on a length of 12½ feet. Two cavalry horses abreast, with their riders leading them, would occupy 12 feet, and the total weight would be abou 2640lbs. A medium 12-pr. brass gun and its limber occupies 14 feet without the horses, and its weight is about 5000lbs. including the limber and ammunition. A brass 9-pr. or 24-pr. brass howitzer weighs about 4200lbs., and a light 6-pr. or 12-pr. howitzer about 3003lbs. (For the weights of Ordnance and Carriages, see the first volume.)

In crossing temporary bridges, cavalry should always dismount, and infantry should never be allowed to keep step: cattle should be driven over in very small numbers at a time.

TEMPORARY BRIDGES.

11. The following resources for facilitating the passage of troops across rivers are added to the article 'Bridge, Field.'

Large trees may be felled to enable infantry to cross a narrow stream, placing them so that their butts may rest upon the banks with the tops directed obliquely up the stream: if one is not long enough, others may be floated down so as to extend across, being guided and secured by ropes: a footway may be formed by laying planks or fascines or hurdles over them, and their branches should be chopped off nearly to the level of the water, and interlaced below; poles also may be driven into the bed of the river, to aid in supporting the trees by attaching the boughs to them.

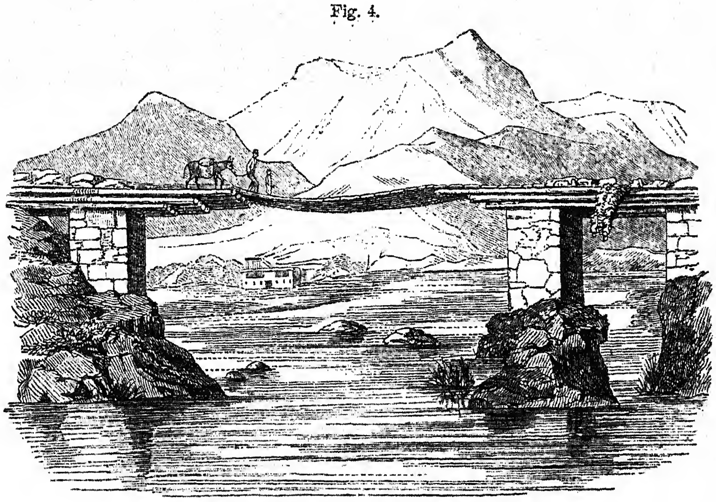
12. *Wheel carriages* may be used to form a foot-bridge, if the river is not too

* In many cases the form fig. 3 is best. Mark off any distance A M, in prolongation of X A; from M, pace in any direction M N bisecting the distance with a picket at P; from A, pace to P, and continue the same distance to D. Pace again in continuation of N D to O, where P and X are found to be in line. D O = A X.—*Ed.*

deep, being pushed or hauled into the stream, and connected by beams; or a single pair of wheels, with an axle-tree to admit two strong posts, may be attached and placed in the centre of the stream, if not too wide, and poles reaching from each bank may be secured to the posts, and the wheels would act as a trestle: with a flooring over the poles, a slight bridge could rapidly be constructed.

13. *A Wicker Bridge.**—"The bridge across the Zab at Lizan is of basket-work; stakes are firmly fastened together with twigs, forming a long hurdle, reaching from one side of the river to the other. The two ends are laid upon beams resting upon piers on the opposite banks. Both the beams and the basket-work are kept in their places by heavy stones heaped upon them.† Animals, as well as men, are able to cross over this frail structure, which swings to and fro, and seems ready to give way at every step. These bridges are of frequent occurrence in the Tigari Mountains."

Fig. 4.



Wicker Bridge across the Zab near Lizan.

14. *Coracles or Hide-boats*, &c., have been used in India and elsewhere. For military operations on the rivers of the American prairies, they are made of four buffalo hides, strongly sewed together with buffalo sinew, and stretched over a basket-work frame of willow, 8 feet long and 5 feet broad, with a rounded bow, the seams being then covered with ashes and tallow: after being exposed to the sun for some hours, the skins contract, and tighten the whole work. Such a boat, with four men in it, only draws 4 inches of water. They have been found very useful in the passage of rivers in Southern Africa. Skins of bullocks were always obtainable; these were stretched over a rude frame-work made from boughs cut on the banks of the river. They were constructed of two sizes:—

1st, Nearly similar to those now in use in Wales. One or more were employed, on commencing the passage of the river, in getting the rope across the stream to work the

* From 'Nineveh and its Remains,' by A. H. Layard, Esq.

† For a military operation, probably a rope extended across the river on each side of the hurdles would be better.—*Ed.*

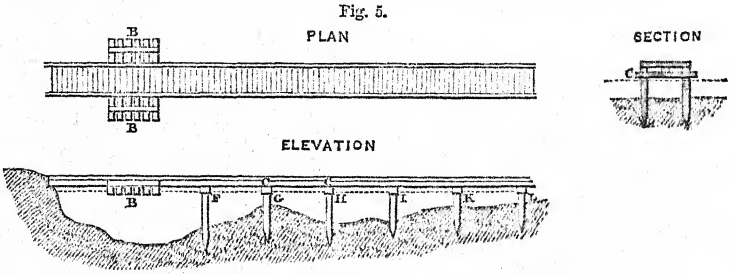
raft of casks, and afterwards in helping the bullock waggons across, or in ferrying over men or small stores.

2nd. The boat was often increased in size, so as to hold two or three men. The arms and ammunition were ferried over in them. The raft of casks was by this means enabled to be dispensed with, the remainder of the baggage being taken over in the bullock waggons. Valuable time was thus saved in ferrying 400 or 500 men over a swollen river.

15. *Inflated Skins* have been used since the earliest times for crossing rivers; and if four or more are secured together by a frame they form a very buoyant raft. *Canvas*, rendered waterproof, and stretched over a frame-work or wicker-work, will serve also as a raft or pontoon. The detachment of Royal Sappers and Miners at Sandhurst made some wicker-work or gabion pontoons in the following manner: Light poles were fixed upright in the ground in a circle, and brush-wood weaved upon them exactly as is done in making gabions, a scaffold being of course required for the workmen to stand upon when the weaving was too high for them to work from the ground; and the conical ends were added afterwards, made of the same materials. When the canvas was stretched over this wicker-work, it was payed over with a composition of pitch 8 lbs., bees'-wax 1 lb., tallow 1 lb., boiled together, and laid on quite hot; the cracks which appeared on its hardening being closed by means of a hot iron.

16. *Pile Bridge.*—"On the 16th July, 1809, two companies of the Staff Corps were directed to make a bridge across the Tietar River, near Placentia in Spain, where the profile of the river was found as explained in the following diagram.

Fig. 5.



The dotted lines show the water level.

"The only materials at hand were the timber of a large house about half a mile from the place. This building was unroofed and the following were found available:

6 beams of dry fir, 2 feet square and 20 feet long;
400 rafters, 6 by 4 inches, and 10 feet long;
6 large doors; and
200 running feet of mangers.

"Of the six large beams the raft B was made by boring holes through the centre of each, towards the ends, and passing ropes through them; this raft was placed in the deepest part of the stream, and the broad ends turned towards the current; one end of the rope was made fast to a tree on the bank, and the other to a stake. A working party of 500 men, with saws and axes, were sent to a distance of three miles to procure young pine-trees to cut the piles and caps, as shewn at C in elevation and section of diagram; and the horses,* ten in number of two piles each, were fixed as

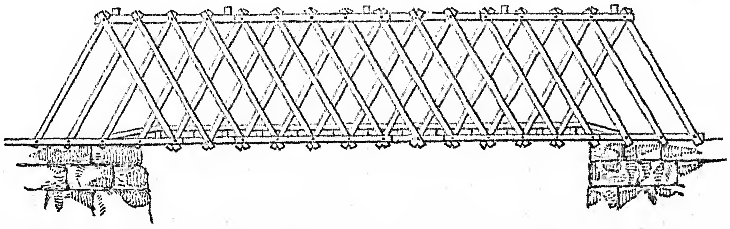
* It has been explained in another part of this work, that among carpenters and sawyers the horse has only two legs and the trestle four.

explained at C; the bearers E, F, G, H, I, K, L, made of the baulks, were laid on the caps of the horses, cut into scantling of six inches square. The flooring of the bridge was made of the doors, mangers, and rafters, which were found sufficient." *

17. *Temporary Bridges of Gun and Mortar Platforms.*—As the power of crossing streams which separate the various corps investing a fortress, or placed in position to resist an attacking army, is often of vital importance, and may even decide the result of a campaign, Lieut.-Colonel Bainbrigge, Royal Engineers, has suggested, that whenever materials for gun or mortar platforms are provided preparatory to the attack or defence of a fortified position, or any fortified place, they should be prepared in such a form as also to admit of their being made use of for the construction of bridges, rafts, &c. To attain this object he has proposed that they should consist of baulks 10 feet long and 4 by 3½ inches, adapted to the construction of platforms similar to those invented † by the late Colonel Alderson, R.E., which may be rapidly framed into various kinds of bridges adapted to the nature of the streams to be crossed, by substituting for dowel-pins and holes, intended to connect them, iron or oaken pins, from 10 to 20 inches long, and ¾ inch diameter, to receive which each baulk must have five holes ⅞ths of an inch in diameter, bored through it at equal distances apart whereby they can be connected and formed into solid platforms; and by screwing nuts into the ends of the iron bolts, these baulks may be converted into bridges, without alteration or injury to their capacity for again forming platforms for guns and mortars; and the following different descriptions of bridges which can be made solely of platform materials were tried in 1846, at the Royal Military Repository, Woolwich, and were approved by the Officers of the Select Committee ordered by the Master-General and Board to report upon them.

18. *First, a Trussed Lattice Bridge,* as shewn in the diagram below, fig. 6, having a span of 28 feet, consisting of two separate frames, which were put together on the bank and hauled into their places by ropes,—which might perhaps be facilitated by stretching hawsers across, upon which they might slide; five baulks were lashed across over the tops of these frames when fixed perpendicularly in their places, 8 feet apart, so as to brace them together. Baulks were also placed with their ends resting

Fig. 6.—Elevation of side of Lattice Bridge.



on the lower string-pieces of each frame, to support the flooring for the roadway, which, for want of a sufficient number of baulks, was composed of pontoon chesses: the bolts were only applied along the top and bottom of each frame, as marked in the figure, thus requiring 72 bolts and 102 baulks. An 18-pr. gun with its limber, weighing 65 cwt., was drawn over this bridge without causing any appearance of weakness, and other experiments shewed that a similar bridge, constructed with half

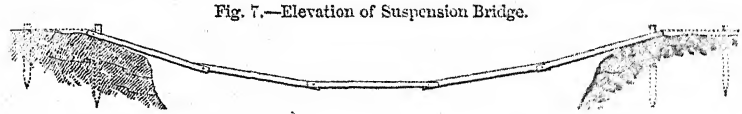
* Notes from Papers of the late General Sir George Murray, Quarter-Master-General.

† See article 'Battery,' vol. i.

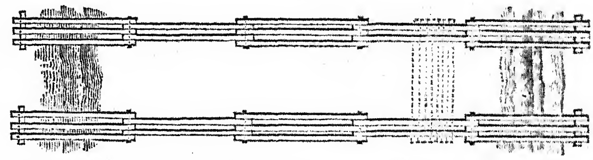
the proportion of crossed baulks in the side frames, and with a span of 50 feet, would suffice for the passage of 6-prs.; and that probably, if the lower edges were strengthened with additional baulks or ropes, 12-pr. guns might cross with safety.

19. *Secondly, a Suspension Bridge.*—The baulks of the platform were fixed in strings as follows, spanning 32 feet, laid down 7 feet apart, and parallel: baulks were also

Fig. 7.—Elevation of Suspension Bridge.



Plan.

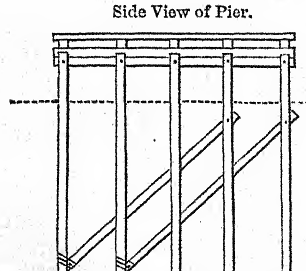


laid across the strings, so as to support the roadway: the ends of each string, having been hauled tight, as explained in fig 7, by a block tackle, were secured by pickets driven into the ground, against which the bolts connecting them rested; but they might be attached to trees or to rocks, &c., if found more convenient. Each set of baulks was connected with the ends of the next set by a single bolt, therefore only 12 bolts are required for this bridge; and supposing (as in the lattice bridge) that the flooring baulks were placed 2 feet apart, and the roadway formed of planks or pontoon chesses, only 48 baulks are required for it. A 12-pr. brass gun, with its limber, weighing 36 cwt., was taken over it without causing any appearance of weakness, and one string of baulks was also loaded with $37\frac{1}{2}$ cwt. (equivalent to 75 cwt. on the whole bridge) without causing any effect except a slight depression resulting from the yielding of the pickets, which were not sufficiently firm: these were fixed as shewn in dotted lines in the elevation of the bridge, fig. 7.

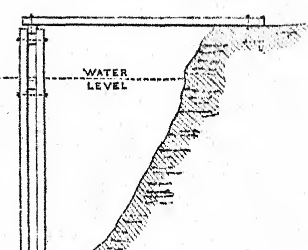
20. *Thirdly, a Trestle Bridge*, one pier of which, as shewn in fig. 8, is first framed together and placed perpendicularly in its position by launching it out from the

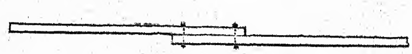
Fig. 8.—Trestle Bridge.

Side View of Pier.



End View of first Pier.



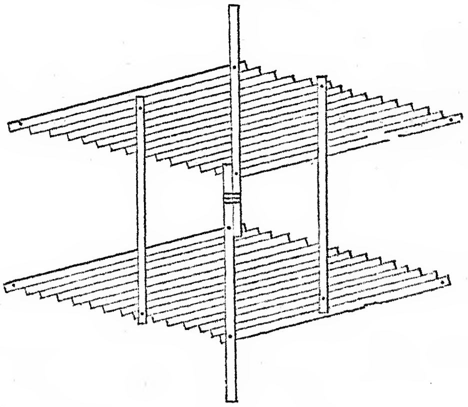


shore over two poles. The trestle, when framed as above, being loaded at the bottom

with stones, is boomed out by means of baulks attached to its top by lashings, which secure it in its position, and support the roadway when fixed : similar piers are then placed in succession 9 feet apart, and iron pins may be used to secure the baulks connecting the piers, which also support the flooring. Supposing, as before, that this is composed of planks, 85 baulks and 68 bolts are required for a bridge of this kind, 40 feet long. Such a bridge has a great advantage over ordinary trestle bridges, in presenting a very narrow surface to the current, and thus preventing floating trees or ice from collecting against the piers, and carrying them away; for greater security against which, the sides may also be boarded over. As this bridge appeared capable of supporting any weight required, no guns were taken over to try it, the ground being inconvenient for that purpose. Ice-breakers formed of similar baulks, fixed so as to form a sloping edge, over which the ice would rise and break itself, may be added to each trestle.

21. *Fourthly, Rafts.*—Platform baulks were rapidly framed into a light raft, as explained in fig. 9, consisting of two or three layers of baulks, crossing each other, and joined together by others bolted to them above and below, so as to form a diamond-shaped raft, which was found to be capable of being rapidly paddled about by one man; and by connecting two of these together, as shewn in the following diagram, a more capacious one was constructed, which supported a 6-pr. brass gun; and by adding others on each side, a continuous bridge can be formed, in which case the rafts may be further apart. A single raft, consisting of two layers of baulks, requires only 33 baulks and 4 bolts, and may be put together in an hour by four men.

Fig. 9.—Plan of Raft.

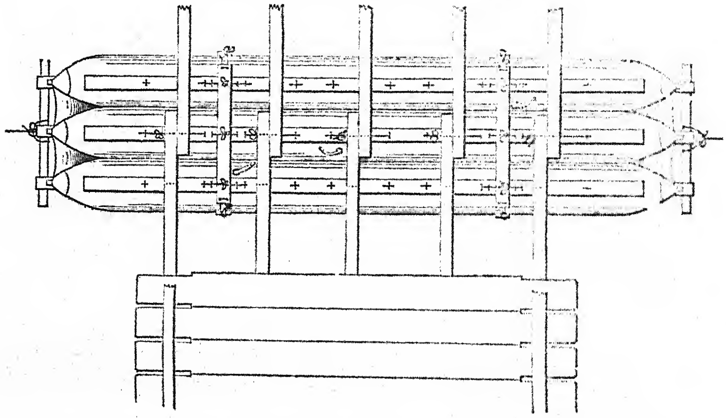


These four experiments, tried by Lieut.-Colonel Bainbrigge at Woolwich, and explained in paragraphs 18, 19, 20, and 21, shew how timber of very small dimensions can be applied in the Passage of Rivers, and will suggest methods of using materials of very irregular scantling and lengths, which may be put together with pins of hard, tough wood, instead of iron.

22. *Vulcanized India-rubber Pontoons.*—The following account of this description of floating bridge is extracted from the fourth number of the Papers published by the United States' Military Engineers in 1849. These pontoons would prove particularly useful where transport is difficult, as each pontoon, consisting of three cylinders connected together, weighs only 260 lbs., and with a flooring of three chesses is capable

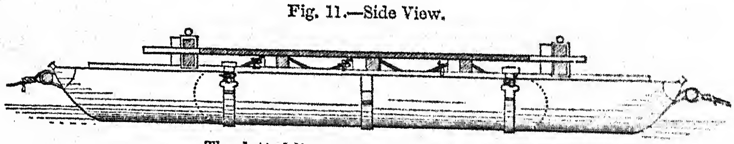
of being paddled about for the purpose of casting anchors, &c. (see fig. 10), and can packed in a box 5 ft. × 3½ ft. × 1 ft.

Fig. 10.—Plan of India-rubber Bridge.



23. "The India-rubber pontoons are made of India-rubber cloth, and consist each of three tangent cylinders, peaked at both extremities like the ends of a canoe: the ends are firmly united together by two strong India-rubber ligaments which extend along their lines of contact, and widen into a connecting web towards the ends, in proportion as these diminish,—the whole thus forming a single boat 20 feet long by 5 feet broad, of great buoyancy and stability, and from its form and lightness presenting but trifling resistance to the water. Each cylinder, including its peaked extremities, is 20 inches in diameter, and is divided into three distinct air-tight compartments (see fig. 11), each of which has its own inflating nozzle. The middle

Fig. 11.—Side View.



The dotted lines shew the compartments.

compartment occupies the whole width of the roadway of the bridge. The pontoon nozzles are made of brass, as shewn in detail in fig. 12, and are in two parts, the stopple and tube, the former screwing into the latter, to open or close the nozzle; the

Fig. 12.—Section of Nozzle.

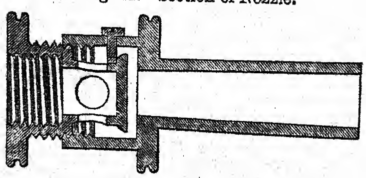
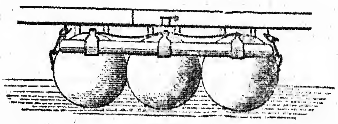


Fig. 13.—End View.



tube consists of two cylinders of different diameters, but having the same axis. The stopple is a hollow cylinder, with four circular openings on the sides, for the

ingress and egress of the air, and is closed at the lower base by a flat cap, a little larger than the diameter of the cylinder, so that the projection catches against a small side-screw, to prevent its coming out; though, by first removing the screw, the stopple can be taken out if necessary.

24. "*The Frame and Roadway of an India-rubber Pontoon.*—The frame lies on the top of the pontoon, to which it is lashed (see figs. 10, 11, and 13), and serves as a means of attaching the baulks to the pontoon, and preventing their chafing it; the baulks are of white pine or spruce, 19 feet long, $4\frac{1}{2}''$ wide, and $4\frac{1}{2}''$ deep; the chesses are also of white pine or spruce, 13 feet 9 inches long by $1\frac{1}{2}$ foot and $1\frac{1}{4}$ inch. (See figs. 10, 11, and 13.)

25 "*Manufacture of India-rubber Pontoons.*—The pontoons are made of two thicknesses of strong, heavy cotton duck, coated with metallic rubber, the outer thickness being coated on both sides, and the inner thickness on its outer side only, making three rubber surfaces or layers. In preparing the caoutchouc gum for coating the duck, it is first cut into small pieces, and carefully washed to rid it of all dirt and impurities, and is then passed between two grinders, iron cylinders revolving with different velocities, and heated by steam to about 150° Fahrenheit, and then mixed with white-lead and sulphur, in the proportion of 25 lbs. of gum, 10 lbs. of white-lead, and 3 lbs. of sulphur. When the rubber becomes plastic, and is well mixed with the sulphur and white-lead, it is laid aside, and, after a few days, is again passed through a second series of revolving cylinders, more nearly in contact, and heated like the first; and after it is made perfectly homogeneous, and about as soft as putty, by this second grinding, it is passed through a third set of revolving cylinders, longer than the width of the duck to be coated. Upon one of these cylinders a thin sheet of rubber is formed, which is brought nearly in contact with another cylinder, over which the duck is passed from a drum round which it is wound. By the compressing power of these cylinders, the rubber is so forced into the meshes of the duck, and firmly united with its surface, that it cannot afterwards, without difficulty, be removed. In like manner several additional thin sheets of rubber are placed upon the cloth. The coating of the other side of the duck is similarly executed, and, if designed for the outside of the pontoon, a little colouring matter is added to the rubber, to make it dark, the natural colour of the gum being a light yellow. Inflating nozzles, one opening into each compartment, are inserted in the pontoon: the bellows for inflating the pontoon does not differ, except in the formation of the nozzles, from that in ordinary use.

26. "*Repair of India-rubber Pontoons.*—The greatest danger to which these India-rubber pontoons are exposed is that of being perforated by the musket-balls of an enemy opposing the passage of a river. Should a shot-hole be made in a pontoon while forming the bridge, it may be temporarily stopped, without removing the pontoon from its place, by an India-rubber patch, a few of which the pontonier-serjeants should always have in their pockets. The patch is made of two circular pieces of India-rubber cloth, 3 inches in diameter, having a small hole in the centre, through which passes a string of soft cord, knotted at one end, which will completely fill the hole. One of the circular pieces is crowded into the pontoon, and drawn tight against the inside of it by the patch-string, where it is kept in its place by the inner pressure of the air, while the other circular piece is slipped over the string hard against the outside of the pontoon, and secured in place by tying a knot close to the outer surface of the patch. Larger holes could be stopped in a similar manner, but would, of course, require larger patches. For the repair of small shot-holes, the torn edges should be trimmed, making the opening of the inner thickness of the pontoon, say about an inch in diameter, while the outer thickness should be removed for a dia-

meter of 3 inches, and all the old gum (which, after being vulcanized, will not adhere to new) carefully scraped off from the outer surface of the inner thickness for the same diameter of 3 inches, and from the outer surface of the outer thickness for a diameter of 6 inches. The hole being thus prepared, three or four coats of India-rubber cement, thinned, if necessary, with a little camphine, are put on the inside surface of the pontoon by the finger or a brush, for a width of about 2 inches around the hole, each coat of cement being dried in the shade before the next is put on. A patch of strong duck, 5 inches in diameter, and coated on one side with cement, is then adjusted on the inside of the pontoon, so that the centre of the patch will correspond to the centre of the hole: a second patch, 3 inches in diameter, and coated with cement on both sides, fills the openings cut out of the outer thickness of the pontoon; and a third patch, 6 inches in diameter, of vulcanized India-rubber cloth, coated on one side and cemented on the other, is put concentrically over all."

27. *Observations on India-rubber Pontoons.*—The equipment and management of these pontoons are nearly similar to the means employed for bridges of a different kind, the floating portion constituting the only essential difference; and this being light and compact when folded up, its transport will be easily effected. Looking at the equipment of the whole in the Service of the United States' Government, it appears too large and unwieldy to accompany an army, except in countries where the roads are good. As regards the floating portion of these pontoons, several diagrams have been given to explain its nature; and it presents so many advantages, that it will probably be adopted in our Service, with some modifications in the equipment. Similar pontoons were used by a party of Royal Sappers and Miners under Serjeant M'Leod, of that corps, at the Cape of Good Hope, during Lieut.-General Sir Harry Smith's expedition against the Boers in 1848; and by means of two of them, when formed into a raft, horses, artillery, and waggons were ferried over the Orange River when in flood and very rapid.* (See also article 'Pontoon,' page 135.)

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* In the bridge constructed by Lieut.-Col. Nicholson, R.E., across the Gogra, near Fyzabad, in October, 1857 (R.E. Corps Papers, vol. viii. p. 94), 75 boats of various sizes were employed, eleven of which were from 1500 to 2000 maunds, or about 53 to 72 tons burden, twenty from 600 to 900 maunds (21 to 32 tons), and the remainder smaller. On one half of the bridge, the baulks of large scantling, 9"×4", or 8" ×5", and 20 feet long, were laid in the ordinary way, five abreast, spaced out to support a roadway 12 feet wide, and covered with 3" plank, the greatest bearing of the baulks being 10 feet. In the remaining portion of the bridge the boats were placed only 3 feet apart, their cross beams or thwarts were wedged up underneath, baulks laid across the beams to obtain the same level as in the other boats, and bamboos were then laid side by side, lashed to the thwarts, and covered with 1½ inch boards. No skilled labour of any kind was required, and the roadway was exceedingly light. As a test, some of the bamboos were laid with a 10 feet bearing, and supported two large elephants standing side by side, the width being, as before, 12 feet. When crooked, the bamboos were soaked in oil and straightened over a slow fire. The bridge was 470 yards long. The cables employed were made of long grass twisted on the spot, and the anchors were formed of pieces of timber halved together at their centres with bamboos stuck in them, and drawn together at top in form of a pyramid, matting being placed round them to retain the stone used for weighting the anchors. Major Crommelin, Bengal Engineers, at the passage of the Ganges in 1857, employed boats of various sizes, but all flat-bottomed, with sloping sides, pointed at both ends, and rising slightly to stem and stern, from points distant from them about one-third of the boat's length. These boats were from 30 to 50 feet long, and 12 to 15 broad. The peculiar feature of this bridge was the causeway, which was necessary on account of the great width of the inundation between the road and the main channel, varying from 2 to 6 feet in depth. For this purpose a number of platforms, which had been used for a road across the sands, were collected together. These were 8 feet by 6 feet, and formed of 3" planks spiked to sleepers 4" square. In the more shallow parts, two rows of platforms were laid side by side on the bottom, and weighted with clods of earth. On these other rows were placed and weighted in like manner till the necessary height was gained, when all the top was well covered with grass to fill up crevices, and the whole covered

PART II.—PERMANENT BRIDGES.*

This little essay is not intended for the experienced Engineer, it having been originally written to afford a few simple rules to those who, without the advantages of professional education, are frequently called upon to superintend the construction of bridges in India. I have confined myself at present to the consideration of bridges of masonry as being most generally useful, and I have used the plainest forms of calculation; thus enabling any overseer, tolerably well acquainted with the rudiments of arithmetical computation, to solve the few problems required.

In calculating the thrust of the arch, I have omitted the effect of weight of the arch itself in steadying the pier, as the introduction of that element would place the question beyond the reach of ordinary mathematicians. The treatise may be useful to local committees in the construction of ordinary bridges; but when large rivers have to be dealt with, the advice of a Professional Engineer should be taken, as there are many points of local consideration which will occur to the practised mind alone.

SECTION I.—EQUILIBRIUM.

Equilibrium of an arch is that condition in which all its component parts balance each other, and are thus enabled to remain at rest without the aid of friction or of cement.

2. In general practice it will be necessary to consider equilibrium merely as it affects the abutments or supports of the arch. This *result* of equilibrium is called 'the thrust' of the arch.

3. It is indeed possible so to construct an arch with roadway, that the fabric shall destroy itself: such was the arch built by William Edwards in his second attempt to span the River Taaf. His arch was a semicircle of 140 feet diameter. The deep haunches being filled in with solid masonry, proved heavy enough to force up the central portion, when of course the whole building fell. This is an extreme case, and could only occur with semicircular or Gothic arches, and of very large span; and such arches may even be rendered perfectly safe by piercing their haunches with openings, or by using other methods (hereafter shewn) to lighten them.

4. This overloading of the haunches is the greatest danger to which the arch itself is subject, and although it applies with little force to arches of flattish outline, yet modern architects usually reduce the weight upon the haunch, not only with reference to equilibrium, but with a view to decrease the expense of the work.

5. With the above precautions duly observed, and with others of form and thickness, &c., which will be mentioned in their proper places, we may assume as a practical truth, that if an arch be properly supported at its feet, it will stand firmly. This leads us to the subject of Section II., viz. 'the thrust of an arch.'

SECTION II.—THRUST.

Professor Barlow has shewn that the lines of thrust in all arches follow certain curves which are of the parabolic class, the exact species of that class being deter-

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with 6 inches of earth, making a roadway 12 feet wide. In the deeper parts brushwood was laid in in bundles and trodden down in a tolerably compact mass, yet still allowing the water to percolate. Over the brushwood the platforms were built up as before. The total length of causeway and bridge was about 1¼ mile (R.E. Corps Papers, vol. viii. p. 104).—*Ed.*

* By Major-General Sir F. Abbott, C.B., Bengal Engineers.

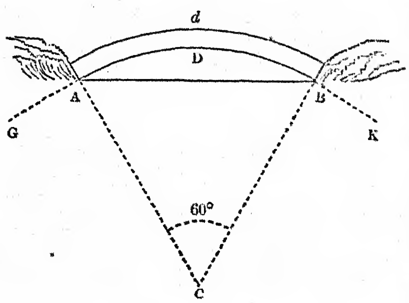
mined by the nature of the loading. The common parabola is, however, the most generally known; and as its errors are all on the side of safety, it is particularly convenient for our purpose: we may therefore assume this rule.

Rule. The thrust at any point of an arch is always in the direction of a tangent to some parabola at that point.

2. It is not necessary to exhibit here the several methods of constructing a parabolic curve, the properties of which are generally understood by Professional Engineers.

3. It is found, on comparing the parabola with the circle, that the two curves very nearly correspond up to a certain length; and that about 60 degrees of every circle may be *practically* assumed as the upper portion of some parabola; so that by confining ourselves to the use of 60° of a circle, we have an arch, whose line of thrust may be immediately obtained by drawing a tangent to the circle, or a perpendicular from the radius at its intersection with the circle. See fig. 1, where A D B is an arc of 60°, and the lines A G, B K, perpendicular to the radii C A, C B, respectively, are tangents to the circle, and represent the line of thrust of the arch.*

Fig. 1.



4. Beyond the extent of 60°, the line of thrust becomes tangent to that parabola of which the arc A D B forms the summit. Without adverting, in this place, to the method of finding the thrust, we will see how the arc of 60° can be turned to account in most practical cases.

5. In a segmental arch of 60° the radius is equal to the span,—the rise of the arc, or 'versed sine,' as it is called, is between ⅐th and ⅛th of the span,† which, although less than is usual in India, is common in Europe.

6. Draw another curve from the same centre C, but with longer radius, so as to represent the thickness of an arch of masonry; then, if the feet A and B stand upon rock, we have a substantial arch in equilibrium, or of such a nature, that if each of the arch-stones had its sides radiated towards the centre C, and if, instead of mortar, something even greasy or slippery were introduced between the joints, the arch would still remain firm.

7. Having ascertained the direction of the line of thrust of the arch, fig. 1 or 2, *i. e.* the angle that this line makes with the horizon, we can compute with tolerable accuracy the amount of force with which the arch pushes in a horizontal direction against its abutments.

Rule. Find the solid content of the arch from which its weight can be computed; then multiply half this weight by the cotangent of the angle of inclination of the line of thrust. The product will be the horizontal thrust of the arch upon *each* of its abutments.

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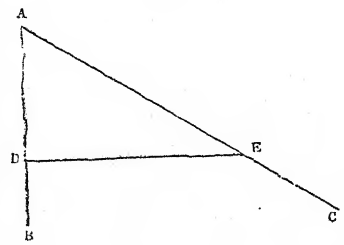
* To find C, the centre for describing the arc,—take the length A B in the compasses, and with centres A and B describe two arcs cutting each other at C.

† The rise or versed sine is found by multiplying the span into the decimal fraction ·1339746. This applies only to the segment of 60°,—in other cases multiply the radius by which the arc of 60° is described into the same fraction, or refer to a table of natural versed sines.

8. To work out the question by lines, so as to avoid the use of Mathematical Tables, draw any vertical line A B; from A draw A C, making the angle B A C equal to the difference between 90° and the angle of inclination that the line of thrust makes with the horizon. Set off on A B, from a scale of equal parts, half the weight of the arch in pounds, cwts., or tons, from A to D; draw D E perpendicularly to A B, to cut the line A C at E; then D E, applied to the same scale of equal parts, will shew the horizontal thrust. (See fig. 2.)

Fig. 2.

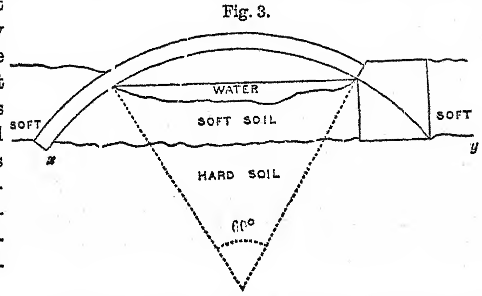


SECTION III.—ABUTMENTS.

In figures 1 and 2 we have arches striding from bank to bank of the river, the natural soil being supposed to be firm enough to bear the weight and thrust of the arches. But as such soil is seldom found in practice, it becomes necessary to build a mass of masonry, called an abutment, at each end of the arch, and these abutments must be founded upon substantial soil.

2. If the line xy (fig. 3) represent a stratum of solid soil, clay, rock, or gravel, &c. lying below softer earth, it would appear necessary merely to continue the parabolic curve down to the line xy: but in such a case an injurious strain would be occasioned by the superincumbent mass of earth; it is therefore necessary to give upright abutments, although at a considerable sacrifice of material.

Fig. 3.



3. The springing line of an arch should be kept as low as possible, compatible with safety and convenience; as by such precaution the mass of the abutment is reduced. The height of the springing line is, however, regulated by circumstances. When there is no traffic upon the river, the springing line may be a few inches above the highest possible floods; remembering that the construction of a bridge will frequently raise the floods above any previously experienced.

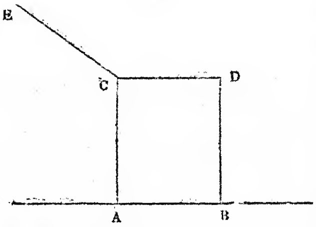
4. Where rivers are used for navigation, the abutments must be sufficiently raised to admit of towing paths; and the arches must be sufficiently elevated to allow loaded boats to pass freely beneath them.

5. Any unnecessary addition to the height of an arch or an abutment not only wastes material, but causes either an awkward ascent or the necessity of additional approaches.

6. Having fixed according to circumstances the height of the springing line of the arch, as well as the height of the roadway, it becomes necessary to determine the thickness that must be given to the abutment, to enable it to resist the thrust of the arch. This is a very difficult part of the Engineer's art; and judging from the extraordinary diversity observable in works of the most celebrated architects it would appear that scarcely two of them had been guided by the same rules or principles.

7. An abutment may be considered as a compact mass, A B C D, (fig. 4,) liable to be moved from its position, either by being turned over on its heel B by the thrust along the line E C, or by sliding on its base A B. When the abutment is lofty, it will be more likely to turn on its heel; when low, it will be more likely to slide. Resistance to the first motion is comparatively easy of estimation. Resistance to sliding is a problem involved in much obscurity, for want of a complete knowledge of the laws of friction; we can, therefore, in this latter case work only by approximation.

Fig. 4.

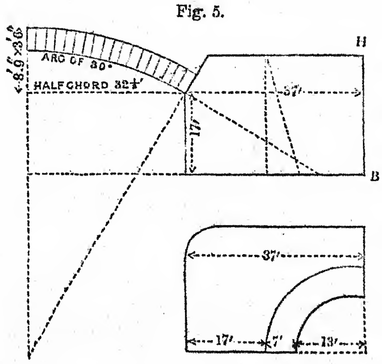


8. The resistance of the abutment against turning on its heel B is (independently of the earth behind it) represented by the mass of the abutment A B C D multiplied into half its thickness, or half A B: but if we suppose the arch and abutments to be composed of the same sort of stone and brick, we may then dispense with solidity, and work by surfaces; which method will be more convenient.

9. The proposed method of determining the thickness of an abutment to resist the effort of an arch to turn it over, will be best illustrated by an example.

10. The abutment arch of the Hutcheson Bridge, Glasgow (fig. 5), built by Mr. R. Stevenson, is a segment of 60 degrees of a circle, the radius and span being each 65'. The line of thrust, which is tangent to the circle at the springing, forms therefore an angle of 30° with the horizon. The thickness of the arch is everywhere 3' 6". The height of the springing line is 17', but the abutment is carried up solid to a mean height of 26 feet.

Fig. 5.



11. To find the thrust of the arch, it will be requisite to allow for the roadway and occasional loading of the arch; and when the material is stone, 18 inches added to the thickness of the arch will cover all. The arch then is 5' thick, and the length of the half-arch is 35'; and $5 \times 35 = 175'$ is the area of the half-arch; this, multiplied by the cotangent of 30° or $1{\cdot}732 = 303{\cdot}1$, is the horizontal force acting upon a lever 17 feet long; therefore the total force to be resisted by the pier will be $303{\cdot}1 \times 17 = 5152$.

12. To find the thickness of abutment necessary to resist the above thrust,—let H be the height of the abutment, and B its thickness; then $H \times B$ will represent its area; and supposing this, as in the area of the arch, to represent the weight also, we have to multiply it by half the thickness, or half B (by the laws of the lever).

Therefore $H \times B \times \frac{1}{2} B$ or $\frac{H \times B^2}{2}$ will represent the vis inertiæ of the abutment.

Now to make this just balance the thrust, we have the equation

$$\frac{H \times B^2}{2} = 5152;$$

from which the value of B will be found to be 19·6 or 19′ 7″, which is almost exactly what Mr. Stevenson has given to the solid part of his abutments.

13. The above thickness enables the abutment just to balance the arch and its load, but it is advisable to have a preponderance in favour of the pier: this may be given by the addition of buttresses called 'counterforts.' Mr. Stevenson has made those in the example before us very massive; they are two buttresses 17′ long and 12′ mean thickness, with a horizontal counter-arch between them. I should, however, deem it safe to give four counterforts, each having a length equal to one-third or one-half of the thickness of the abutment, and a breadth equal to one-tenth the breadth of the same.

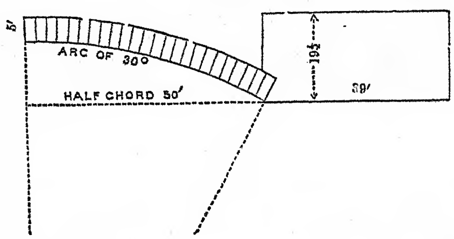
14. The above example was taken from a number of plans of bridges, merely because the arch happened to contain 60° exactly. The Wellesley Bridge at Limerick corroborates this theory very closely; the calculated value of B being 13′ 10″, whilst the thickness of the solid part of the abutment, as executed by Mr. Nimmo, is 15′; and there are also three counterforts, each 6′ long and 4′ broad. But on the other hand, the Bridge of Jena in Paris, being a segment of 54′ with a chord of 91′ 6″, and versed sine of 10′ 9″, and where the value of B is calculated at 28 feet, the architect, M. Lamande, has given the enormous thickness of 45 feet, or half the span of the arch. Such profusion of strength is not to be imitated.

15. When the arch is elliptical, the line of thrust will be calculated as a tangent to a parabola from the point where the parabolic curve cuts the abutment produced upwards.

16. With reference to the second mode of failure, viz., by the abutment sliding upon its foundation, Mr. Rennie's experiments with roughly dressed granite seem to show that the friction with this stone is somewhat greater than half the weight; and taking into consideration the tenacity of the cement, the resistance afforded by the two may, with safety, be considered as equal to three-fourths of the weight, if not fully equal to the whole. However, limiting the effects to three-fourths of the weight of the abutment, we will suppose the following case:

17. Let fig. 6 represent one-half of a segmental arch of 60°—the whole span being 100 feet, and the thickness of the arch, or depth of voussoirs, being 5 feet. The rise or versed sine will be $13\frac{1}{2}$, and the surface of roadway may be 2 feet above the key-stone, so that the total height of the abutment will be $13\frac{1}{2} + 5 + 1 = 19\frac{1}{2}$ feet. The thrust falling at the foot of the abutment, it is plain that it will be more likely to slide upon its base than to turn over upon its heel. The force or horizontal thrust will be $6\frac{1}{2} \times 50 \times$ cotangent $30° = 576$; and the equation of equilibrium will be

Fig. 6.



$$H \times B \times \tfrac{3}{4} = 576;$$

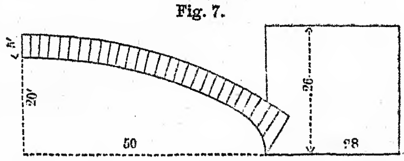
where H is the height of the abutment, and B is its length $= a\,b$, then

$$B = \frac{576}{H} \times \frac{4}{3};$$

and as $H = 19{\cdot}5$, B will equal 39 feet, nearly. Some little allowance may be made for the sake of safety.

18. In figure 7, where the rise is one-fifth of the span, the value of H is 26, and this reduces the value of B to 28.

Fig. 7.



19. That the thrust of an arch is exceedingly diminished by the tenacity of the masonry, when consolidated, was shown by an accident which occurred very recently with an old bridge of considerable size. The valley, which is extensive, is crossed partly by the bridge and partly by a viaduct pierced at intervals by small arches.

20. In the rains of 1842, one end of this bridge, 130 feet, consisting of six small arches standing on box-work 9′ deep, was undermined, together with a portion of the causeway. The waterway being considered insufficient, it was proposed to substitute a set of arches, varying from 30 to 21 feet span, in place of the injured portions of the bridge and causeway. The overseer in charge, by some strange oversight, proceeded to dismantle the injured arches, without taking any precaution towards supporting the next sound arch (a semi-ellipse of 30′ span and 7′ versed sine), which was thus left abutting on a pier 6 feet thick and 11 feet high. Such an abutment was much too weak, and under the thrust of a fresh arch would have been overturned: but the old arch merely opened a little underneath the key-stone, and threw the abutment slightly out of the perpendicular. A heavy buttress was then applied, until the new companion arch could be turned (a semi-ellipse of 31 feet span). On the centering of this new arch being struck, the pier resumed its original position, and the crack of the old arch closed up.

21. This example is instructive, inasmuch as it shows that one-fifth of the span is not sufficient for the *abutment* of an elliptic arch of similar span, rise, and supports; and these proportions are very commonly used in regard to piers.

22. It is not recorded, that any opening or crack took place between the springing and the crown of the above arch, which, according to some theoretical writers, ought to have been the case: however, it is by no means certain that such an intermediate crack did not take place.

23. I have omitted from the calculations all consideration of the steadiness imparted to the abutment by the *vertical* pressure of the arch; this element would render the subject too abstruse for the ordinary builder; nor do I believe that it has ever been considered *practically*.

SECTION IV.—PIERS.

A pier is an abutment supporting the feet of two, instead of only one arch: it then ceases to be an 'abutment;' as the horizontal portions of the thrust of the two arches *abut* against and balance each other, leaving only the vertical or perpendicular portion of the thrust (which is simply the weight) to be borne by the pier.

2. Now the weakest material of which a masonry bridge is constructed, viz. brick, is so strong in resisting a crushing force or weight, each square foot being estimated as capable of bearing about 80,000 lbs. weight, or 35 tons, that a pier two feet thick would (without other considerations than that of the mere weight) suffice to support the feet of two arches of 200 feet span each, and 2 feet thick or deep.

3. In practice, however, arches meeting on a pier do not always counterbalance each other completely. The pier, if very thin, would be rickety, and liable to be split or bent by the load, although the bricks themselves would not be crushed: it is therefore usual to give a much greater thickness to piers, than is absolutely necessary for supporting the load.

4. Some Engineers consider it necessary, that a pier should be strong enough to act as an abutment to the other arch, in the event of one arch being broken: but this would generally require the pier to be one-third or one-fourth of the span; and this would interfere too much with the waterway. One-fifth and one-sixth of the span are both practised in India; and they give a light and elegant pier. This thickness is measured at the summit of the pier.

5. It is a good practice to build piers with a slope or 'batter,' thus making the thickness greater at the foot of the pier. This not only imparts steadiness to the pier itself, but causes it to oppose a greater surface against the soil, rendering it less liable to sink. This slope or batter need not exceed 1 in 12. With low elliptic arches, it is common to give a considerable batter, but in the form of the curve (*vide*

Fig. 8.

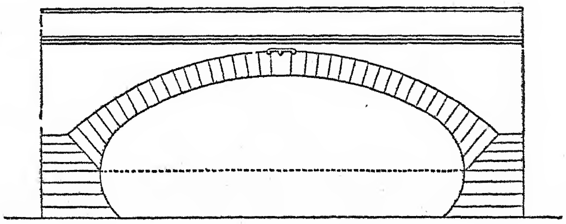
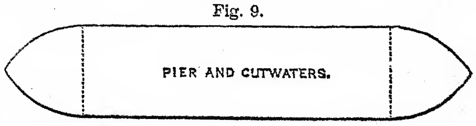


figure 8), which gives a very elegant appearance: but it reduces the waterways, and is only allowable on particular occasions.

6. In running streams of any magnitude it is advantageous to shape the ends of the piers into cut-waters, for the purpose of passing the water through the arch with as little turmoil as possible. The best form for such purpose would be that of a very sharp wedge,* but this would be weak in itself and dangerous to boats. A very good form (fig. 9) is obtained by describing arcs from each corner of the pier with a radius equal to the thickness of the pier. In small bridges, or where the current is slack, it will be sufficient to describe semicircles on the ends of the piers as diameters, as in fig. 10.

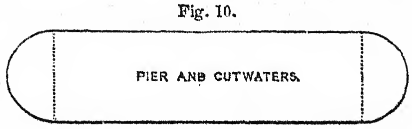
Fig. 9.



7. Piers should be built in a very solid manner and with very fine joints, to obviate settlement.

8. The summit or head of a pier should rise above the highest flood level.

Fig. 10.



SECTION V.—THE ARCH.

There are only two curves well adapted to bridge purposes, viz. the segment of the circle and of the ellipsis or oval. The first is the simplest: but a constant repetition of it would be tedious to the eye, which requires variety; and this is afforded by the ellipse and its modifications.

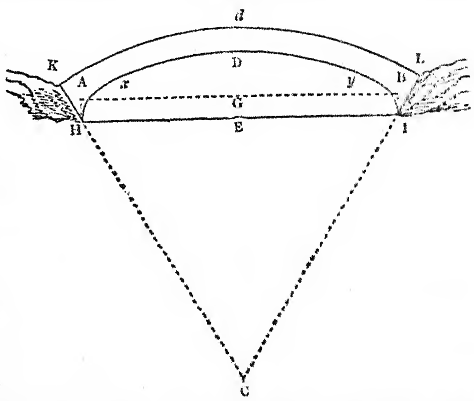
2. There are many ways of drawing an oval: but, passing them over, we will here see how the segment of 60° may be converted into an oval, so nearly resembling the true ellipse, as to be hardly distinguishable from it, even on measurement. (Fig. 11.)

3. Draw the arc A D B as in fig. 1; draw the perpendicular radius C D, and upon it

* Mr. Page's cut-waters in the New Westminster Bridge appear to be of this form.

set off D E equal to about one-fifth of the span A B. Through E draw H E I parallel to A B, making A H, B I, equal to half G D. From the points x and y, taken at about one-fourth of the half-arcs A D, B D, draw by the aid of the eye the curves x H, y I, to complete the oval. This is a very graceful curve, and has a very convenient rise: its thrust is exactly the same as in figure 1.

Fig. 11.



4. To obtain the back or 'extrados,' after having determined the depth of the key-stones D d, take C d as radius, and from the centre C describe the arc K d L.

5. The voussoirs or joints are all drawn towards the centre C.

6. The form of the arch may be varied by making the versed sine D E greater or smaller in proportion to the span.

7. One of the most graceful arches in Europe is a semi-ellipse, whose rise is less than one-sixth of the span; it is built of marble. The arches of the town bridge on the canal at Kurnaul, built by Colonel J. Colvin, of the Bengal Engineers, are of similar proportions, and are built in brick. Very flat curves require care and attention in setting the joints accurately: but care and attention should be bestowed upon every arch, however simple its form.

8. Gothic, Mohammedan, and other pointed arches are not well suited for bridges, as they require a more than convenient rise, besides being mechanically objectionable.

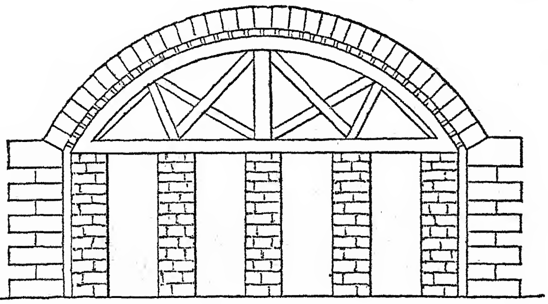
9. *Thickness of Arch*, or the depth of the key-stone.—Authorities and examples differ very much in regard to this fundamental. Key-stones, which generally denote the depth of the arch at the crown, have been actually constructed from $\frac{1}{10}$th to $\frac{1}{47}$th of the span. If it were necessary to guard against dead weight or thrust simply, the depth of arch actually necessary would be very small; but as vibration is one of the most dangerous enemies of a bridge, it becomes expedient to give such solidity as to reduce this action within safe limits. In large arches of stone, $\frac{1}{30}$th of the span, or thereabouts, is a favourite depth of key-stone with modern architects; but this would be much too small in small brick arches of 30′ and 40′ span. Brick being lighter than stone, and the compressive force of a small arch being much less than that of a large one, the equilibrium would be more easily disturbed by a passing load. For brick arches of 40 and 50 feet span, $\frac{1}{18}$th of the span will be found a good thickness; for 30′ spans, $\frac{1}{15}$th; for 20′ spans $\frac{1}{10}$th; and for 10′ spans $\frac{1}{5}$th: it is false economy to allow less than 20 or 24 inches to the smaller bridges or culverts.

10. *Turning the Arch.*—Preparatory to turning the arch it is necessary to provide a form or 'centering' on which to lay the bricks or stones of the arch itself. In Europe centerings are made of timber: but in India, where timber is generally scarce, and the spans of bridges usually small, pillars of mud-cemented masonry are built between the piers or abutments; and on these may be laid either a wooden frame coinciding with the form of the intrados of the arch, or a form of brick and mud-work. *Vide* figures 12 and 13.

11. Such centres will only be applicable to arches which can be turned with certainty before the periodical floods take place. Where this is not possible, piles

must be substituted for the pillars; or centres of timbers must be made, which will stand by resting upon the piers. These latter require considerable mechanical skill and are very expensive.

Fig. 12.

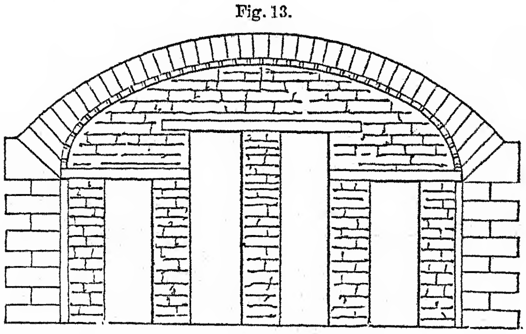


12. Upon the moulded surface of the centre, the arching bricks are laid, commencing at the haunch and taking care to make the two sides approach equally towards the centre, and to leave a space at the centre just sufficient to receive one brick as a key-stone. This brick or key should be inlaid with finely ground mortar and be driven home with a few light taps of a wooden mallet: care must be taken not to use too much force, or the arch will perhaps start near the haunches.

13. *Joints.*—All the joints should be radiated at right angles with the curve of the parabola; but where only 60° of a circle are employed, the bricks are all radiated to the centre of the circle. When the span is 20′ and upwards, it will be needless to dress each brick to the form of the arch; it will suffice to make the joints as small as possible, recollecting that the bricks should be in actual contact, the cement merely filling up their inequalities.

14. When the arch is keyed or completed, the centering may be removed. This operation should be performed by excavating the earthen mould from below the centre of the arch, working thence towards the haunches, and by equal gradations on either side of the centre; otherwise the arch might settle unequally, and be strained.

Fig. 13.



15. *Bonding.*—As far as 40 feet, a very simple mode of bonding the masonry of an arch has been found successful. The bricks are all laid on edge with the centering, and are carried round from pier to centre in concentric rings: horizontally they break

joint across the arch. Arching of this pattern is hardly more expensive than common wall-work, but it is found to be inapplicable to very large spans.

16. The most usual mode is that of the common bond. One brick is laid on edge to the centering, its length laying in the direction of the breadth of the arch; the next brick is placed with its end upon the centering and its length in prolongation of the radius, thus breaking joint on the thickness as well as on the breadth of the arch.

17. *Cements.*—One of the best cements ordinarily to be obtained in India is made of one part stone lime and two parts fine *soorkee* or pounded brick ; *bujree* or gravel being seldom fine enough for arch joints. The lime should be fresh and caustic; the soorkee should be made of the soundest bricks. The two ingredients should be mixed and ground dry under a *chuckee* or grinding-stone, and should then be slaked with just sufficient water to make them into a paste. If fine bujree be used, the same mode of treatment is to be observed. The quality of the cement depends greatly upon the lime being slaked from its caustic state whilst in contact with the gravel or soorkee.

18. *Haunches.*—To relieve the shoulders or haunches of the arch from unnecessary weight, as well as to save material, thin longitudinal walls, called "spandrel" walls, are built at intervals, extending from the abutments nearly to the centre: their summits support either slab-stones for covering the intervals, or small vaults of masonry.

19. These walls may be 1½ or 2 feet in thickness; their intervals, where flags are used to cover them, must depend upon the size of the stone procurable. When vaulting is used, the intervals may be 3½′ or 3′; the outer walls in this case should not be under 2 feet.

SECTION VI.—ROADWAY.

On roads of great traffic, and when the bridges are small, they should be the full breadth of the road. But when the bridges are large, this would cause them to be too expensive ; they should not, however, be less than 24 or 25 feet in clear width of roadway between the parapets.*

2. A flat or level roadway is the most convenient: but where a rise is necessary, the slope should not exceed 1 in 35, or 1 foot of rise to 35 feet of base.

3. Above the extrados or back of arch there must be laid a course of bricks on edge, fixed in mortar, and over this a layer of 6″ of metal (beat down from 9″). This surface should be well drained by means of outlets through the parapet walls.

4. The roadway should always be guarded by parapet walls, varying from 3 to 5 feet in height and from 1½ to 2 in thickness, according to the nature of the bridge. These walls are continued with a curved splay outwards from the end of the bridge, to form proper entrances or approaches.

SECTION VII.—TREATING OF THE FOUNDATIONS FOR BRIDGES, ESPECIALLY IN INDIAN RIVERS.

Hitherto I have considered the abutments and piers as standing upon solid soils, their bases being spread out to give a better footing; but in India it too frequently happens that this precaution is not sufficient. The general character of the earth's crust, in India, is a superstratum or upper layer of clay, varying in quality by its

* This applies to Indian roads.

mixture with sand or vegetable mould, and varying in thickness from 3 feet to 20, or even more, with a substratum of sand to great depths, but generally containing thick or thin layers of clay, or *kunkury* clay, lying at various depths below the surface of the sand.

2. When rivers run in the upper stratum of clay without cutting through it, their streams will generally be found to be sluggish, having little slope, and running across or obliquely with the general line of drainage. With such streams it will be necessary merely to sink the footing of the piers and abutments a few feet below the bed of the stream; but where the clay has been cut through, exposing the sand, it becomes necessary to take further precautions for fixing the feet of the piers and abutments.

3. Sand, when free from the action of running water or other disturbing forces, is by no means a bad foundation; it is superior to many kinds of clay: but in the bed of a river, and under even the most gentle current, it is liable to be moved, and is therefore quite unfit for the footing of piers, &c.; and it becomes necessary to seek artificial means of securing the foundations.

4. With small bridges, and where the current is not very strong, and where the natural waterway has not been much diminished by embankments, it is sufficient to support the bridge upon 'boxed foundations.' These are formed by making large boxes of wood of the shape of the pier or abutment, but about 9″ or 12″ larger each way as to length and breadth. The boxes have neither tops nor bottoms, and their sides vary in height from 6 to 10 feet, according to circumstances. These boxes are driven into the sand by scooping from the interior, and they are then filled with rubble masonry. Upon this masonry the piers and abutments are built.

5. Beyond the depth of 10 or 12 feet, it is better to use wells or blocks of masonry.

6. Wells* are familiar to the natives of India, who have used them as foundations for many centuries. The class called Well-sinkers are very expert; almost any Raj Mistree will lay off the walls of a foundation. When a cut-water is used, care must be taken to have it also supported by a well or part of a well.

7. 'Blocks' are a variety of the well foundations. In this case a frame of stout wood, well joined, is made in the shape of the pier or abutment, being a little wider each way. Upon it is raised a mass of masonry, conforming to the shape of the wooden frame or 'Ny-chuck.' The masonry is pierced by wells, varying from 3′ to 5′ in diameter, and placed at various distances; but the largest wells should not be more than 3 feet apart; when the pier or abutment is very large, it may be divided into two or more portions. These masses are driven down after the manner of well-sinking; they are capable of being well loaded, and they may be sent downwards with great nicety, and are not so apt as wells are to topple over. They are more expensive than wells, but are much firmer.

8. Blocks may be laid at distances of 8 and 10 feet, the intervening spaces being covered by arches: this is economical in large works.

9. A Table is given of the rates and times of block-sinking, compiled by Major W. E. Baker, of the Engineers, from the day-books of work at a canal bridge.

10. The following remarks apply equally to wells or blocks.

11. These foundations may be supported in two ways, either by driving them down to the solid soil,—clay or kunkur, or rock,—or they may be suspended, as it were, in the sand, by mere friction, the force of which is very great in sand; so much so, that beyond the depth of 40 feet or so the labour of sinking the masonry becomes excessive, and unless the head be well weighted by extraneous loads, there is great chance

* See 'Corps Papers,' vol i. p. 50.

that the lower portions will drop away into the hollow formed by the excavators; but by heavily loading the summit, wells have been driven 50 feet through sand.

12. If the river's bed were not disturbed to any great depth by the action of the water, there would be no necessity for sinking the wells very deep; friction alone would suffice to uphold them; but Indian rivers have this peculiarity, that during eight months of the year they occupy very narrow channels, and during the rest of the year they flow with broad and rapid streams, sometimes overflowing the country for miles on either side.

13. It would be too expensive to carry a bridge over the whole or even one-half or one-third of this flood: it is therefore usual to embank the greater portion of the low ground with a stout mound of earth, restricting the river to such a channel as we may have the means of bridging.

14. Such reduction of the waterway causes the water to rise in a heap above the bridge, and this occasions a rush or rapid through the arches, sufficient to tear up the sand to a great depth; so that shallow foundations would be rooted up.

15. The uprooting force of these rapids extends to great depths, as is shown by the following facts:

16. In 1831 a masonry bridge of three arches, each of 60′ span, was built over the Neem Nuddee, on the road between Futtehgurh and Koel. The river there runs in a wide shallow valley, and for eight months in the year has no stream, being nearly dry: it takes its rise below Boolundsher, about 35 miles above the bridge, and as it is hemmed in between the Ganges and the Kalee Nuddee, it cannot drain a greater area than 150 square miles; yet in the rains of 1838 the floods came down with such violence, that they rose above the crowns of the arches, and then excavated the soil below the foundations, until the whole mass, excepting the abutments, fell into the gulf.

17. The arches were flat ellipses, springing low, and with splayed piers, described in Section IV. par. 5. The foundations were wells, sunk to the depth of 20 feet, and were supposed to rest on good clay.

18. The eastern Kalee Nuddee takes its rise in a swamp close to Kotowlee, Mozuffernugger district, and about 25 miles north of Meerut. It is like the Neem Nuddee above described as to its valley, and its dry-weather appearance. The slope of the bed does not exceed 14 inches per mile; the river drains an area of about 250 square miles.

19. Over this river and on the Gurhmooktesur road, close to Meerut, a masonry bridge of three arches, each of 25 feet span, was built in 1840; it was supported on wells running down $22\frac{1}{2}$ feet below the river's bed, and supposed to rest upon a strong stratum of clay, mixed with kunkur.

20. In the rains of 1842 a heavy flood occurred; the water rose 8 feet perpendicularly: it did not reach the crowns of the arches, but it rushed with such violence as to scoop out the sand to a depth of 23 feet, or 6 inches below the footing of the wells. The wells dropped perpendicularly 6 inches, and there stood (it is supposed) on the real kunkur-bed: the bridge did not fall, but the arches split into many fissures. On attempting to remove the arches, the whole went down into the pool. Had the pool been filled with sand previously to this attempt, the foundations might have been saved, but would hardly have been trustworthy.

21. Too much caution can hardly be used in ascertaining, by personal inspection, whether the wells have reached a solid stratum. Native workmen, anxious to get this laborious part of the operation over, generally try to persuade the architect that the wells are firmly footed. I think it highly probable, that the wells of the Kalee Nuddee bridge had been stopped just 6 inches short of the solid soil; and that 6 inches more of sinking would have saved this useful construction.

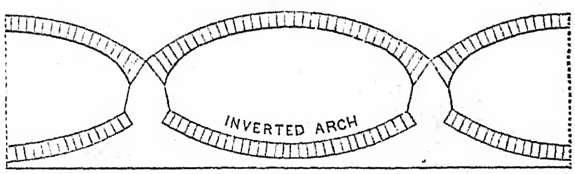
22. The piers of a suspension bridge of 400 feet waterway had been completed on the Hindun river near Delhi, and the abutments had been connected with the high bank by an earthen causeway, measuring a mile from end to end, when, in the rains of 1844, the waters rose 11½ feet, and scooped out the sand from the eastern end to the depth of 25½ feet. The pier at which this occurred stands upon wells, as do all the rest; but the wells of this one, after having been driven to the depth of 34 feet, moved with so much difficulty as induced the architect to stop the work, leaving them supported by sand alone. Great apprehension was entertained regarding this pier, whose wells were actually bare of all but water, to the depth of 25½ feet: they remained firm, supported by the friction upon 8½ running feet of their lower extremities: sand-bags were thrown in, and before the occurrence of another flood the pool was filled up.

23. In Europe, wooden piling is used to a considerable extent in securing foundations: but it is not often applicable in India, as it is necessary to the durability of the piles, that they should be completely covered by water at all times; and in large rivers, where they might be so submerged, the great depth of sand, sometimes 50 feet, is beyond the reach of the largest timbers procurable in the Upper Provinces,—nor could the pile be driven to that depth in many cases,—timber piles might be scarfed: but they would be more expensive than wells, which are nothing more than piles of masonry.

24. Piling, however, is often used as an auxiliary in defending the feet of causeways and the wing walls of bridges; also in protecting the curtain walls where flooring is given below the arches: but all these are on a small scale, and the subject requires little notice. In driving piles, it is better to use a heavy weight with a short drop, than a light weight with a long drop: by the former the work is more speedily executed and the pile-heads are less injured. When driving piles in sand, especially quicksand, the blows should be given as quickly as possible; the moment the pile ceases to vibrate, the sand settles around it, and lessens the effect of the next blow. The longer the intervals between the blows, the less will be the effect of each. A pile half-driven in sand, and left for any length of time, will be sometimes found immoveable.

25. Instead of using piles or wells or other deep foundations, the piers and abutments of moderately sized arches are supported upon inverted arches, as in fig. 14.

Fig. 14.



These arches, by distributing the pressure over a large area, enable a bad soil sometimes to resist the weight of a bridge, which it could not do if the pressure were concentrated in the narrow areas of the piers and abutments.

26. Such a foundation is only applicable, where the soil is not liable to be moved; for it is evident, that if the soil were washed out from below the centre, the arch at that part would very probably drop down.

27. Inverted arches will sometimes save a weak clay soil from being cut by a rush of water through the bridge. In this case there should be curtain walls, some few

feet deep, drawn across the opening from pier to pier, to prevent the arch from being undermined. A row of piling is sometimes given instead of the curtain wall, but the wall is the best: sometimes both are used, viz. a curtain wall resting upon piles.

28. In large bridges, where water is generally to be found at the very footing of the piers, it would be extremely difficult to turn an inverted arch; and as the soil in such cases of Indian experience is generally sand, the arch would be unstable.

29. In cases where the waterway of a large bridge is found to be dangerously small, the foundations are sometimes secured by a flooring of masonry. This flooring should be 4 or 5 feet thick; and, besides lying between the piers, should extend 20 feet beyond them, both up stream and down; the outer edges being guarded by curtain walls, if possible, or by rows of piles: sheet piling (stout planks of wood would be the best, if procurable at moderate cost). It is better to avoid the necessity for these costly additions by allowing a sufficiency of waterway in the original design.

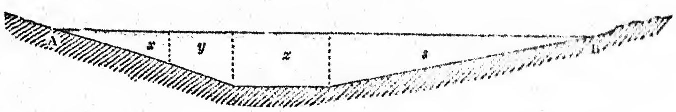
SECTION VIII.—ON THE PROPER WATERWAY FOR BRIDGES.

The most difficult part of an architect's task is, very often, to determine the amount of opening or waterway to be given to a bridge. When the banks are well defined and the river does not overflow, then the question is comparatively easy; but when, as with our Indian rivers, the dry-weather supply is a mere rivulet, or perhaps nothing, and the rainy-season supply a flood spreading over the country, then the question becomes one of very intricate calculation; inasmuch as it is difficult to determine what portion of the water is moving and what is mere back-water. It is seldom that the architect has opportunities of seeing the highest floods; he therefore gathers his accounts from others; or even if he should happen to witness a flood, he may not possess the means of measuring the sections and velocities.

2. An approximate calculation will show a simple mode of making a useful estimate of the quantity of waterway that should be allowed.

3. Let A B (fig. 15) represent the flood-line of a river; it is plain that if we measure

Fig. 15.



the areas of each compartment, x y z and s, and ascertain with what velocity the water is moving through each, we shall know how much water actually passes by in a given time, say a minute or a second.

4. Now, as water flows on account of the slope in the river's bed, if we know the velocities caused by certain slopes, we can calculate what amount of opening must be given to a bridge, to allow the whole of the water of the above section to pass under the bridge at its natural velocity; and so avoid all that *heading up*, which is found so destructive.

5. The *safest* width of opening would, in many rivers, be inconveniently great; we are therefore obliged to run some risk, by confining the floods to narrower bounds: this causes a heading up or 'afflux;' and in proportion to the perpendicular height of this afflux, so will the velocity be.

6. Table III. shows that sand is moved by the smallest velocities, even so little as 6 inches per second, or about one-third of a mile per hour; therefore the beds of our

rivers must be continually moving, and the question becomes, 'to what depth does this movement extend under certain velocities of current?'

7. Experience alone is our guide in replying to the above question; but I regret to say that until very lately, little or no attention has been paid to the subject. From certain data, I calculate the flood mentioned at par. 22, Section VII., to have been about 11 feet per second; and as the effect of this velocity was to scoop out the sand to a depth of $25\frac{1}{2}$ feet, it is plain that any velocity approaching to 11′ per second must not be risked, under ordinary circumstances: I consider a velocity of 5 or 6 feet per second to be dangerous to bridges whose foundations do not rest on firm soil, or which are not carried to very great depths, and this velocity is caused by an afflux or heading up of only 6 inches.

8. The above may appear a small velocity to cause so much damage. Nature has, however, afforded us some clue even in this difficult computation. Captain Sharp, in boring the bed of the Jumna at Agra, came upon broken *bricks* at a depth of 23 feet; and this can only be accounted for by supposing, that the bed has been disturbed to that depth by the natural current of the river. Captain Sharp roughly estimates the surface velocity of the Jumna at Agra to be 8 feet per second at high floods: but from certain data, I do not calculate the *mean* velocity to be more than $5\frac{1}{2}$ or 6 feet per second, and this velocity is caused by the confinement of the flood between two bold banks only 1300 feet apart. The velocity of the greatest flood at Delhi is, probably, much less than 6′ per second.

9. In Table No. II. is given the amount of afflux caused by obstructions in the river's course, and in Table No. IV. the velocities due to those affluxes. If, therefore, the section of the river and its velocities can be accurately measured, the amount of waterway in the bridge, so as not to cause a greater velocity than 5 feet, nor a greater afflux than 5 inches, can be at once taken from those Tables.

10. I have said that very few architects ever have the opportunity of seeing the river in question at its floods; it may then be asked, how can the velocity and discharge be ascertained?

11. Determine by inquiry the height of the highest flood ever known; and correct the information, if possible, by flood-marks.

12. Take an accurate section of the river's bed perpendicularly to the course at the site of the proposed bridge; and calculate the area contained between the highest flood-line and the bed. Do the same at points 1 mile above and 1 mile below the proposed site of the bridge.

13. Measure the length of the undulating line of the river's bed (in each cross section), and divide the area by this length; the quotient will be what is called the 'hydraulic mean depth,' which will be found to vary very slightly from the common mean depth, in most Indian rivers.

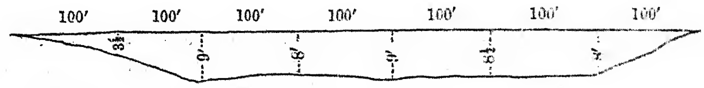
14. Add together the three mean depths so found, and divide by three; the quotient will be the *mean* of the three 'hydraulic mean depths' to be used in the calculations: write it in inches.

15. Ascertain by means of a levelling instrument the difference of level between the upper and lower section; that is, the amount of slope in the river's bed for 2 miles; and write it down in inches.

16. Multiply the hydraulic mean depth in inches by the difference of level just found (also in inches), and take the square root of the product, which will be the surface velocity of the current per second, in inches. Nine-tenths of the surface velocity may be taken as the 'mean velocity.'

17. Knowing the area of the section (the mean of the three areas should be used), we can by reference to the Table No. II. ascertain the afflux which will be caused

by damming up one-third or one-fourth, &c. of the natural area, or waterway, thus :



The area of this section is 4600, and if the length measure 710 feet, then $\frac{4600}{710} = 6{\cdot}48$ feet, the hydraulic mean depth.

18. Let us suppose that the two other mean depths were 6·8 feet and 6·1, then $\frac{6{\cdot}8 + 6{\cdot}1 + 6{\cdot}48}{3} = 6{\cdot}46$, which is the *working* hydraulic mean depth ; and in inches it will be 77·52.

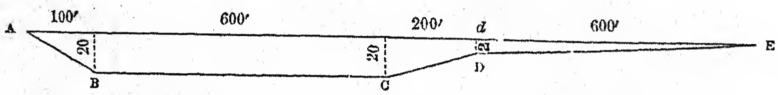
19. Say that the difference of level between the upper and lower sections is 30 inches ; then, $\sqrt{77{\cdot}52 \times 30} = 48{\cdot}2$ inches, which is the surface velocity, and $48{\cdot}2 \times \frac{9}{10} = 43{\cdot}38$ inches, or 3·6 feet, the mean velocity in feet per second.

20. Say that we had proposed to have a bridge of three arches, each of 50 feet span, springing at a height of 9 feet above the bed of the river, then $3 \times 50 \times 9 = 1350$ represents the area of the waterway ; and this is between two and three tenths of the whole mean area of sections ; therefore the *obstruction* will be equal to 7 or 8-tenths.

21. Now enter Table No. II. with the velocity of 4 feet, which is nearest to 3·6, and run the finger along until you come under the column 7-10ths, and you will find the afflux to be 3·2755 feet ; and in the next or 8-10ths it is marked as 7·775 feet ; take the mean, and call the afflux 5·5 feet, and on referring to Table No. IV. you will find the corresponding velocity to be between 17 and 19 feet per second ; which would tear up all but rock.

22. To find the waterway corresponding to the safe afflux of 5 inches (see par. 9), enter table No. II. with velocity 4 feet per second (the assumed velocity of the river before meeting with obstruction), and opposite to it, the afflux 5 inches (·4166 feet) would be between the third and fourth column, showing it to be due to an obstruction of between 3-10ths and 4-10ths of the sectional area : the waterway, therefore, must be equal to 6-10ths of that area : and if the spring of the arches be 9 feet, $\frac{4600}{9} \times \frac{6}{10} = 306$ is the length in feet of the waterway required. If arches of 50 feet span be preferred, there must be six of them instead of three.

23. I have shown the general principle for ascertaining the proper opening for a bridge, but as all hydraulic formulæ have been computed for rivers of tolerable regularity of section, the application of the above principles to our Indian rivers will require modification. Suppose a river to have the following section—



the area of the whole is 15,800 square feet, the hydraulic mean depth is 10·5, or 126 inches. Suppose also the fall in 2 miles to be 10 inches, then $\sqrt{126 \times 10} = 36''$ or 3 feet ; and $15800 \times 3 = 47400$ is the discharge in cubic feet per second, according to the general rule.

24. But if we take the section in two parts, viz. ABCDd as one, and the triangle EDd as the other, and calculate them separately, we shall find a considerable difference between this result and that of our first computation, thus:

25. The area ABCDd = 15200 square feet; the hydraulic mean depth is 16·6 feet or 199·2 inches: then $\sqrt{199 \times 10} = 44{\cdot}62$ inches, or 4 feet nearly; and 15200 $\times 4 = 60,800$ cubic feet per second as the discharge for this one portion alone.

26. The triangular portion has an area of 600 square feet; the hydraulic mean depth is 1 foot or 12 inches; then $\sqrt{12 \times 10} =$ inches, nearly, the superficial velocity: and $600 \times \frac{11}{12} = 550$ cubic feet, the discharge per second: therefore $550 + 60800 = 61350$ is the discharge, instead of 47400, as in the first computation.

27. I have adopted the superficial velocities in these illustrations, but in practice the mean velocities should be used.

28. The architect must use his discretion in calculating different rivers. Some may be taken by the first rule; others may require three or more separate computations or divisions. The calculations belong to plain arithmetic, and with this view I have selected the formulæ of Dr. Eytelwein, a German philosopher, in preference to those by the French Academicians, which are rather abstruse, and are not, I think, one jot more accurate when applied to open rivers. Persons desirous of studying the subject more deeply would do well to consult the 'Encyclopædia Britannica,' or Robinson's 'Mechanical Philosophy.'

SECTION IX.—GENERAL OBSERVATIONS.

Position of a Bridge. Site.—The general situation of a bridge will be determined by the line of road which it is intended to carry, but its exact site should be selected, as much as possible, in conformity with the following views:

1. Bold banks are to be preferred with Indian rivers, as involving less expense in the matter of causeway approaches, and as rendering the direction of the stream more certain.

2. The middle of a straight reach (with regard to flood-stream) should be selected; as, in bends of a river, one bank is under continual erosion; therefore the abutment on that bank would be in danger of being turned by the current.

Number of Arches.—As a general principle, it is better to make few arches of large span than many arches of small span, as involving less trouble in the foundations, and as affording freer passage for floods. Thus a river is more obstructed by two arches of 25 feet each than by one arch of 50 feet span.

Ornament.—Solidity and durability should on no account be sacrificed to appearances. Thus, when brickwork is used, the parapets should be formed f plain panelled masonry, in preference to balusters of pottery.

The arch itself should always be indicated or relieved in some manner, otherwise the opening will look like a hole cut in a wall. In brickwork, this may be done by projecting the arch face 4″ or 6″ beyond the surface of the rest of the masonry, when it may be chiselled into voussoirs or into fillets.

Pillars or pilasters, with entablatures, have been exploded by good taste.

TABLE I.

Daily Progress and Cost in undersinking the Block Foundations of the Indree Suspension Bridge, communicated by Captain W. E. Baker, Superintendent, Canals west of Jumna.

Feet.	Front Abutment. Blocks 12′ 3″ × 10′ 0″, with 4 shafts in each.				Total.	Average	Cost of sinking 100 sq. ft. of Block, in Nos. 1, 2, 3, and 4.			Flank Blocks 12′ 0″ × 8′ 0″, with 2 shafts in each.				Total.	Average	Cost of sinking 100 sq. ft. of Block, in Nos. 5, 6, 7, and 8.		
	1	2	3	4						5	6	7	8					
	Days.	Days.	Days.	Days.	Days.	Days.	Rs.	As.	P.	Days	Days.	Days.	Days.	Days.	Days.	Rs.	As.	P.
1	0·5	0·5	0·5	0·5	2·0	0·5	1	7	8	0·5	0·5	0·5	0·75	2·25	0·5625	1	4	5
2	0·75	0·75	0·5	0.5	2·5	0·65	1	13	7	0·75	0·75	0·5	0·75	2·75	0 6875	1	9	0
3	0·75	0·75	0·75	1	3·25	0·8125	2	6	6	0·75	0·75	0·75	0·75	3	0·75	1	11	3
4	2	1·75	0·75	0·75	5·25	1·3125	3	14	2	1·75	1·5	0·75	0·75	4·75	1·1875	2	11	2
5	0·75	1	1	1	3·75	0·9375	2	12	5	1	1	1	1	4	1	2	4	4
6	0·75	0·75	1	1	3·5	0·875	2	9	5	1·25	1	1·5	0·75	4·5	1·125	2	8	10
7	0·75	1	1	1	3·75	0·9375	2	12	5	1·5	2	1·5	1·5	6·5	1·625	3	11	0
8	0·75	0·75	0·75	0·75	3	0·75	2	3	6	2	2	1·25	1·25	6·5	1·625	3	11	0
9	0·75	0·75	1·5	1	4	1	2	15	4	1·5	1	1·5	1·5	5·5	1·375	3	1	11
10	1	0·75	1	1·5	4·25	1·0625	3	2	4	1·5	1·25	1·5	1·25	5 5	1·375	3	1	11
11	1	0·75	1·25	1·5	4·25	1·125	3	5	4	2	1·75	1·75	1·75	7·25	1·8125	4	1	10
12	2	1·25	2	1·75	7	1·75	5	2	11	2	2	2	2	8	2	4	8	8
13	1·25	1	1·5	2	5·75	1·4375	4	4	1	1·75	2	1·5	1·5	6·75	1 6875	3	13	4
14	2	2	2	2	8	2	5	14	9	2	2	2	1·75	7·75	1·9375	4	6	5
15	2	2	2	2	8	2	5	14	9	2	2·5	2	1·75	8·25	2·0625	4	10	11
16	2	2·5	2	2	8·5	2·125	6	4	8	2·5	3	2·5	2·5	10·5	2·625	5	15	4
17	1·5	3	2	2·25	8·75	2·1875	6	7	8	2	3·5	2·5	2	10	2·5	5	10	10
18	2·5	3	3	2·25	10·75	2·6875	7	15	4	4	5	4	4	17	4·25	9	10	5
19	2·5	3	3	2·5	11	2·75	8	2	3	4·5	5	4·5	4	18	4 5	10	3	6
20	3·5	3	4	2·5	13	3·25	9	10	0	5	6	4·5	5	20·5	5·125	11	10	2
21	4	3	4	3	14	3·5	10	5	10	5	5	5	4	19	4·75	10	12	7
22	3	4	4	3·5	14·5	3·625	10	11	9	5	7	5	5·5	22 5	5·625	12	12	5
23	4	4·5	3	2·75	14·25	3·5625	10	8	9	5·5	5	5·25	7	22 75	5·6875	12	14	8
24	4	4	3·5	2·75	14·25	3·5625	10	8	9	4·5	5	5	4	18·5	4·625	10	8	0
25	6	3	3	3	15	3·75	11	1	8	4·5	5	5	4·5	19	4·75	10	12	7
26	4	4·5	3·5	3·5	15·5	3·875	11	7	7	5·75	8	6	6	25·75	6·4375	14	9	11
27	4·5	6	5·5	5	21	5·25	15	8	9	7·5	6	9	7	29·5	7·375	16	11	7
28	6·5	6·5	5	4·5	22·5	5·625	16	10	6	7·5	7	6	10·5	31	7·75	17	9	3
29	5·5	7	4·5	4·5	21·5	5·375	15	15	8	16	8·5	10	8	42 5	10·625	24	2	0
30	6	5	7	5	23	5·75	17	9	5	12	6	10·5	9·5	38	9·5	21	9	2
31	6·5	6	6	5	23·5	5·875	17	6	4	12	12	15	12	51	12·75	28	15	3
32	10	9	13·5	12	44·5	11·125	32	15	1									
33	12	10·5	13	14	49·5	12·375	36	10	3									

Total cost of sinking 4 abutment blocks, Nos. 1, 2, 3, 4 (12′ 3″ × 10′ 0″ × 4 = sq. ft. 490) = Co.'s rs. 1431 1 3

Ditto 4 flank blocks, 5, 6, 7, 8 (12′ 0″ × 8′ 0″ × 4 = sq. ft. 384) = „ 868 8 7

In abutment blocks, 490 square feet, in 98·625 days, cost 1431 1 3 : therefore 100 sq. ft. in 1 day cost 2 15 4½

In flank blocks, 384 square feet, in 99·6875 days, cost 868 8 7 : therefore 100 sq. ft. in 1 day cost . 2 4 4

Again, 490 square feet (1431 1 3) : : 100, cost 292¼, nearly, for sinking 33 feet, or 8·85 per ft. in depth.

„ 384 square feet (868 8 7) : : 100, cost 226·17, nearly, for sinking 31 feet, or 7·3 per ft. in depth.

N.B.—In considering this Table, it must be remembered that the last few feet in depth are greatly raised above the average, on account of the work being carried into the more solid stratum or footing course; therefore, in applying the Table to greater depths, the last few feet should be reserved as an after-addition to the quotient.

TABLE II.

Amount of Obstruction compared with the virtual Section of the River.

Velocity of current in ft. per second.	1-10th.	2-10th.	3-10th.	4-10th.	5-10th.	6-10th.	7-10th.	8-10th.	9-10th.	
	Proportional Rise of the River, in feet.									
1	·0157	·0377	·0697	·1192	·2012	·3521	·6780	1·6094	6·6389	Ordinary floods.
2	·0277	·0665	·1231	·2108	·3548	·6208	1·1955	2·8378	11·7058	
3	·0477	·1144	·2118	·3618	·6107	1·0687	2·0580	4·8850	20·1504	
4	·0760	·1822	·3372	·5759	·9719	1·7008	3·2755	7·7750	32·0720	
5	·1165	·2793	·5168	·8782	1·4895	2·6066	5·0202	11·9160	49·1535	Violent floods.
6	·1558	·3736	·6912	1·1807	1·9925	3·4868	6·7154	15·9398	65·7518	
7	·2078	·4983	·9221	1·5750	2·6578	4·6511	8·9578	21·2626	87·7080	
8	·2578	·6423	1·1884	2·0299	3·4255	5·9947	11·5454	27·4042	113·0422	Unusually violent floods.
9	·3359	·8054	1·4903	2·5566	4·2956	7·5172	14·4777	34·3646	141·7541	
10	·4119	·9877	1·8726	3·1218	5·2680	9·2190	17·7557	42·1440	173·8440	

EXAMPLE.—The breadth of the Thames is 926 feet. The sum of the waterways, old London Bridge, was 236 feet. The amount of obstruction, therefore, was about ·75 of the entire section; so that a velocity of 3½ feet per second would give a fall of nearly 4·75 feet, agreeing with the actual result.

TABLE III.

Table of Effects of Running Water on Soils.

Velocities.		Effects.
Inches per second.	Miles per hour.	
3	0·170	Will work upon fine potter's clay,
6	0·340	Will lift fine sand.
8	0·454	Will lift sand, coarse as linseed.
12	0·683	Will sweep along fine gravel.
24	1·363	Will roll rounded pebbles 1″ in diameter.
36	2·045	Sweeps angular stones the size of an egg.

N.B.—The velocity at the bottom must be found for comparison with this Table.

TABLE IV.

Table of Velocities due to certain Heights of Head-Water or Afflux.

Height of Afflux. Feet.	In.	Velocity per second. Feet.	REMARKS.
0	1	2·30936	
0	2	3·2659*	* Sweeps angular stones, the size of eggs.
0	3	3·5650	
0	4	4·6186	
0	5	5·1640	
0	6	5·6569	
0	7	6·1101†	† Probable velocity of floods of Jumna at Agra, where the bed has been deranged to the depth of 23 feet. Large volumes of water are required to produce this effect.
0	8	6·5320	
0	9	6·9282	
0	10	7·3029	
0	11	7·6942	
1	0	8·0000	
1	3	8·9443	
1	6	9·9797	
1	9	10·584	
2	0	11·314‡	‡ Scooped sand to depth of 23 feet.
2	3	12·028	
2	6	12·649	
2	9	13·266§	§ Scooped out a gravel bed under Smeaton's Hexham Bridge, on the Tyne, by some account.
3	0	13·856	
4	0	16·000	
5	0	17·889‖	‖ Mr. Smeaton himself said 5′ head-water.
6	0	19·596	
7	0	21·166	
8	0	22·627	
9	0	24·000	
10	0	25·298	

TABLE V.

Natural Cotangents to Radius 1.

Deg.	Cotangents.	Deg.	Cotangents.	Deg.	Cotangents.
1	57·28996	31	1·66428	61	0·55431
2	28·63625	32	1·60033	62	0·53171
3	19·08114	33	1·53986	63	0·50952
4	14·30067	34	1·48256	64	0·48773
5	11·43005	35	1·42815	65	0·46631
6	9·51436	36	1·37638	66	0·44523
7	8·14435	37	1·32704	67	0·42447
8	7·11537	38	1·27994	68	0·40403
9	6·31375	39	1·23490	69	0·38386
10	5·67128	40	1·19175	70	0·36397
11	5·14455	41	1·15037	71	0·34433
12	4·70463	42	1·11061	72	0·33492
13	4·33147	43	1·07237	73	0·30573
14	4·01078	44	1·03553	74	0·28674
15	3·73205	45	1·00000	75	0·26795
16	3·48741	46	0·95569	76	0·24933
17	3·27085	47	0·93251	77	0·23087
18	3·07768	48	0·90040	78	0·21256
19	2·90421	49	0·86929	79	0·19438
20	2·74748	50	0·83910	80	0·17633
21	2·60509	51	0·80978	81	0·15838
22	2·47509	52	0·75355	82	0·14054
23	2·35585	53	0·73128	83	0·12278
24	2·24604	54	0·72654	84	0·10510
25	2·14451	55	0·70021	85	0·08749
26	2·05030	56	0·67451	86	0·06993
27	1·96261	57	0·64941	87	0·05241
28	1·88073	58	0·62487	88	0·03492
29	1·80405	59	0·60086	89	0·01745
30	1·73205	60	0·57735	90	INFINITE.

PART III.—PERMANENT BRIDGES.*

SECTION I.—STONE BRIDGES.

Ever since the construction and properties of the arch began to be understood, stone has been the material in most general use for bridges of any size and importance.

The full or semicircular arch was the one formerly most common ; but now that it is considered desirable to lessen the ascent of the roadway of a bridge, the flat segmental, the elliptical, and the oval are usually employed. Of these, the latter is the form which admits of the greatest waterway with the same span and rise. It is formed of several arcs of circles, usually about five, of which the curve at the springing lines should be less than that of the ellipse, and the radius of the arc at the crown should not be more than one and a half times the span.

The form of the arch or arches, and the number of piers having been decided on, the work is commenced by excavating for the piers and abutments, till a solid foundation is obtained either on the rock or hard gravel ; or should the soft earth descend to any depth, it will be necessary to drive piles and spike planking upon them, or else to fill in the whole space with concrete : sometimes both piling and concrete are employed. The ordinary mode of laying the foundations of the piers is by means of a coffer-dam enclosing the whole space of the footings, but it is sometimes accomplished by sinking caissons or frames filled with stone or brick ; and of late the diving-bell has been often used.

Each abutment has to bear the weight of half an arch with its roadway, and in addition must be sufficiently strong to counteract the horizontal thrust, which may, however, be almost entirely avoided by commencing the radiating or skew-back courses from the very foundation, the rock being cut something in the form of the skew back of an ordinary arch. This method is followed in the bridge of the Rialto at Venice, and the Grosvenor Bridge over the Dee at Chester. When this is done where the soil is such as to require piling, the piles should be driven in a direction perpendicular to the lowest radiating course, the thrust from which would otherwise be apt to force them in a lateral direction through the yielding earth around them. Driving the piles thus would undoubtedly be at first difficult, and consequently expensive, but it has been done, and may be made an easy operation by having a machine for the purpose.

Plate I. fig. 1.

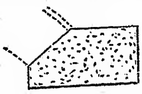
Abutments are usually formed with counterforts, and when extending any distance they often have land arches constructed in them, to lessen the quantity of material. On railways these side arches are very useful as giving the means of viewing the line for some distance in advance.

In large arches the abutments and piers should be entirely faced with cut stone. The filling in or backing should be of large rubble, carefully laid and well grouted at every two or three courses. The upper courses should be of large blocks of cut stone, well cramped and bonded. All cramps in stonework of importance should be of copper, as iron corrodes and becomes loose. If the abutments extend far into the stream, the waterway should be gradually lessened by means of water-wings built out in a curved form from the bank to the back of the abutment.

Each pier has to support the weight of two semi-arches, but no horizontal thrust, which is counteracted or destroyed by the two opposing arches. The least thickness of a pier at top must of course be twice the depth of the voussoirs at the springing

* By Capt. Binney, R.E.

line, but in practice they are generally made much thicker, to allow for ordinary wear from the waves, bad workmanship, and other casualties. The foundations of the piers are formed in offsets, on which the feet of the centres are supported while the arches are being built. The piers and starlings generally have either a rectilinear or curved batter. The latter project about half the thickness of the pier, and are carried up to the highest water-line, and finished above with a single stone or saddle-backed coping, called a 'hood.' They are built of the same materials as the piers, of which they are simply continuations, either in a triangular or parabolic form, to lessen the backwater and permit the stream to pass through more freely.



When the radiating courses are not carried down to the foundations of the abutments, and at all times in the piers, it is necessary to form the skew backs of blocks of stone cut as in the annexed figure, and well cramped to the other work, to prevent their slipping.

When the Engineer has arrived at this point, he may proceed with the arch or arches, having first arranged his centres, which should be constructed during the building of the piers. This is not the place to give a lengthened description of the different forms of centre in use, but it will be well to offer a few remarks on the subject. Some Engineers give the centre a slight increase in rise over the intended arch, in order that a settlement may not cause the crown of the arch to sink below the level originally intended. In building the bridge over the Dora Riparia at Turin, Mosca made the rise of his arch 18·0446 feet, and that of the centre 18·9015 feet, the span being 147·6 feet; and on the completion of the work, the soffit of the key stone was only $2\frac{3}{8}$ inches above the intended height. The centre used for Chester Bridge consisted of four distinct sets of radiating struts supported on trestles, the wedges being carried on the outer rim in such a manner as to admit of easing the different parts of the arch as required, to prevent undue settlement. This form has the disadvantage of obstructing the opening between the piers in rivers much navigated. In centres of the ordinary forms, with the double wedges placed under each rib, the most serious consequences have resulted from the men being obliged to go underneath to ease the arch; but this may be avoided by making the wedges run the whole length from one outer rib to the other, so that they may be eased by men on each side without danger. For a bridge of three arches, two centres are required; and for one of five arches, three centres.

The planes of the arch-stone joints must be perpendicular to the curve of the soffit. The stones are laid in straight lines from one face of the arch to the other, bounded by parallel lines called 'bed joints;' the line of stones being called a 'course' or 'string-course.' The joints in the transverse direction are called 'cross-joints,' and are not continued throughout, but break joint in the adjacent string-course, to prevent lateral disruption. Various modes have been adopted with the view of preventing

Figs. 1 and 2.

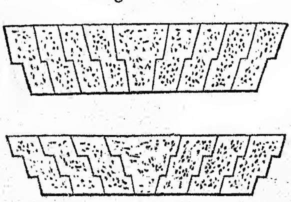


Fig. 3.

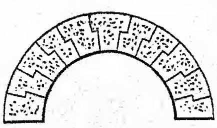
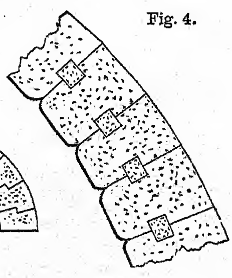


Fig. 4.



the voussoirs slipping on one another. Old arches have been found of the annexed forms, and in fig. 4 (Blackfriars Bridge) the voussoirs are united by means of joggles consisting of a cubic foot of hard stone, let half-way into each joint. The mortar should be thin and well tempered, and when the stones are all laid, the joints at the back should be examined, and, if open, filled with pieces of slate and grouted.

To prevent the joints opening or the stones cracking on removing the centre of the Chester Bridge, the course above the springers was laid on a wedge of lead $1\frac{1}{2}$ inch thick on the face, running to nothing at the end of the bed, and thin strips of lead were introduced in all the joints, over about two-thirds of the soffit, to where the pressure was supposed to change to the back of the arch-stones. "In setting the key-stones, three thin slips of lead were hung down on each of the stones between which they were to be inserted, and the key-stone, being smeared with a thin putty of white lead and oil, was driven down with a small pile engine." Thus the whole bridge settled without any derangement or injury, the soft and yielding nature of the lead causing the pressure to spread equally over the surface of the joints. Sometimes the edges of the voussoirs are bevelled off a little to prevent chipping.

The key-stone is generally from $2\frac{1}{2}$ to 4 feet in depth, and the arrangement of the remainder of the voussoirs made to conduce to the general effect; thus, when the whole facing of the bridge is of cut stone, the top joints of the voussoirs are usually formed in steps corresponding with the horizontal joints of the backing; and when the spandril facings are of rubble or brick, the voussoirs are generally made of equal or alternate depths.

The spandrils should be built of hammered stone or the best rubble. They are usually raised to about one-fourth of the rise above the piers, and in some bridges are constructed of cut stone, the lower courses being horizontal, and the top forming an inverted arch. The capping of arches should be of flags laid with the bond well formed, or else of concrete, to prevent water soaking through, and should be laid so as to form gutters over the piers, where the water from the roadway is received and carried off by iron pipes through the piers into the river above low-water mark.

The head-walls are usually faced with cut stone filled in between with rubble or small arches to support the roadway; earth was formerly used, but requires a much greater thickness of wall.

A cornice is placed immediately on a level with the top of the key-stone as a coping, to protect the facing from rain; its form must be plain or moulded, according to the size or style of the bridge. It should be formed of large single blocks of stone, and the joint between it and the foot of the parapet should be above the level of the footpath, to avoid the wet settling in it.

The parapet or balustrade should be about 4 feet high, and made to conform to the general architectural effect of the bridge, the exterior finish of which must depend mainly on its position, but should, as a general rule, have a strong solid appearance. This appearance is very much diminished by making a bridge perfectly flat, and it has been considered by many eminent Engineers that 1 in 24 is a very good ascent for the roadway.

The approaches must be so formed as to make the bridge safe and easy of access. When the roadway is but little raised above the natural ground, it is enough to carry out the head-walls a little way into the bank, and face the embankment with dry stone or sod-work; but when there is more than one approach, and the road is much raised, the access must be widened, and wing walls built out from the bridge to support the embankment. These wing walls are either formed by prolonging the head-walls in a curve outwards to the edge of the embankment, or building a straight wall forming an angle with the head-wall. In both cases the wall and parapet are continued down to the foot of the embankment, either in a slope or in steps.

Fig. 1, Plate II. Fig. 1, Plate II., is a longitudinal section of part of Waterloo Bridge, showing the centering. V represents the voussoirs, P, the parapet; I, inverted arch over the spandril courses; B, the walls of brickwork on which the flags (Q) are supported, carrying the roadway material: *a a* are the striking-plates of the centre; *b*, the easing wedge; *c c*, struts; *s s*, stirrups or suspenders in pairs; *i i*, cast-iron sockets to receive the ends of the struts; *p p*, main props resting on the feet of the piers.

Fig. 2. In fig. 2, S is the starling, and H, the hood or cap; D, the spandril. This figure is a longitudinal section of the bridge of Neuilly.

Fig. 3. Fig. 3 is a section through the crown of the arch.

SECTION II.—BRICK BRIDGES.

Many of the old bridges were built of brick, but it is now generally confined to those of small span, as canal and railway bridges. The same general observations apply to these as to stone bridges. The most simple mode of forming the arch is to lay the bricks in half-brick rings, with the joints very close on the under side, taking advantage of the difference of their dimensions to prevent two joints coming above one another. In this case two or three rings are carried on together. Another way is to lay two or three rings of brick on end; but this method is very weak, the only key being formed by mortar or cement.

The utmost caution should be observed not to lay a single brick until it has been well saturated with water, as it will otherwise deposit a coat of sand on the cement, and soon become detached from it.

In a circular segmental arch, it is well to mark the centre by battens carrying a small fixed pulley, round which a line is passed for the purpose of laying the outside bricks of each course at their true angle.

Plate III. fig. 1. A, B, shells. C, block. D, key. The mode of laying the bricks in half-brick rings is thought by many to be very weak from having no bond between the soffit and back of the arch; and hence the following has been recommended as the means of giving strength and bond both ways. The arch should be divided in portions by joints running through to the back, the bricks being laid alternately in shells and in blocks, with the joints running through.

If the arch be not more than 3 feet thick, the thickness may be divided into two equal shells laid in rings, and the thorough blocks should not be more than three or four bricks thick on the curve of the soffit, with the bricks laid on end. The bricks forming the key require to be laid with great care. The soffit course may be formed of a thickness of three bricks laid on end, the next of five, and so on, forming continuous joints.

In all brick arches it is well to lay the second course above the soffit of the key in thin mortar or grout, and to wedge with pieces of slate. The grout may be used by dividing the length of the course into several compartments by bricks laid in mortar, and then pouring in the liquid, which should also be poured over the whole of the arch and abutments.

Plate III. fig. 2. A number of different drawings of railway bridges are given in vol. viii. of the Professional Papers, in one of which (Plate XXIX. fig. 5) the abutments are built in the form of large skew backs, somewhat similar to those of the Chester Bridge, described in the section on stone bridges, and partly supported by piles driven obliquely, as recommended in the same section. This bridge is of brick, with stone foundations and facing. A section of the abutment is shown in Plate III. fig. 2.

Fig. 3. The arches on which the Blackwall Railway is supported, and which appear to bear a large amount of traffic without injury, are circular segments of 30 feet span and 10 feet rise, and are composed of five half-brick rings, with piers 3 feet 6 inches thick. The width of the arches is 26 feet.

Bridges are often constructed of brick with stone skew backs, voussoirs, string-courses, and copings. Sometimes the parapets are formed of wooden posts and rails, instead of solid material; and in this case they are built out on corbels beyond the face of the bridge, thereby saving 1 or 2 feet thickness of masonry, and gaining that additional space for the roadway. Iron rails appear better adapted to the purpose, and are sometimes used. They may be made, at a trifling expense, to conduce very much to the ornamental appearance of the bridge.

It often happens, over or under railroads and canals, that a bridge cannot be built at right angles to the stream or road under it. Bridges of this form are called oblique or skew bridges, the bricks being laid diagonally instead of perpendicular to the faces. (Plate III. fig. 4.)

On the London and North Western Railway, a bridge is built over the road at an angle of 32°. The arch is 21 feet span on the square, or at right angles to the road beneath it, and 39·627 on the face. The acute angle of the voussoirs is cut off at right angles to the face, and the cutting is gradually diminished to the opposite or obtuse quoin, where it vanishes, leaving no angle less than a right angle on the surface of the work.

On the Midland Counties Railway a bridge is built with parallel ribs of brickwork, about 4 feet broad on the square, elliptical, and 42 feet 6 inches span, with a rise of 11 feet. The plan of the abutment thus presents a series of steps, from which the ribs spring. This construction, however, in cases of great obliquity, requires either very thick arches or narrow ribs of brickwork, unless spandrils are introduced to fill up the spaces between the soffit of one rib and the extrados of another. Thus extra expense is incurred.

Sometimes, in oblique arches, the central part is built as a square arch, springing at right angles from the abutments, and the ends left at the acute angle on either side are filled in with courses, the beds of which are worked as for part of a true elliptic arch.

The following Table comprises brick bridges with wooden parapets.

TABLE A.

Brick Bridges over Cuttings; 30 feet wide clear between railings; arches 30 feet span, 1 foot 6 inches thick.

Depth of Cutting, or Height of Bridge.	Excavation.	Concrete.	Brickwork.	Stonework.	Woodwork.
feet.	cubic yards.	cubic yards.	cubic yards.	cubic feet.	cubic feet.
14	98	60	330	402	42
30	112	100	530	465	124
60	915	180	1730	924	280

The following Table shows the difference in quantity of material required for bridges in embankments and in cuttings.

TABLE B.

Brick Bridges in Embankments; width and span as before; thickness of arch 1 foot $10\frac{1}{2}$ inches.

Height of Embankment or Bridge.	Excavation.	Concrete.	Brickwork.	Stonework.
feet.	cubic yards.	cubic yards.	cubic yards.	cubic feet.
19	158	80	405	478
30	278	140	545	395
50	314	157	2290	682

The great quantity of stone in the 19-feet bridge was required for coping to wing walls, which the other bridges have not got. A tunnel bridge, with an arch 2 feet 3 inches thick, in a 40-feet embankment (slopes $1\frac{1}{2}$ to 1), contains 295 yards of excavation, 148 yards of concrete, 751 yards of brickwork, and 653 feet of stonework.

The following is an abstract taken from designs of oblique bridges.

TABLE C.

Brick Bridges in Embankments, at various Angles of Obliquity. Dimensions as in Table B.

Height of Embankment or Bridge.	Angle of Obliquity.	Brickwork.	Stonework.
feet.	°	cubic yards.	cubic feet.
30	80	1122	414
...	60	1198	860
40	80	2000	766
...	60	2394	792
...	40	2598	1017
...	30	3336	1227
50	80	2348	727
...	60	2616	1184

Most of these arches are semicircular, and the piers are, when practicable, lightened by arches in the width of the bridge.

Plate III. figs. 4 to 7.

Figures 4 to 7, Plate III., show an oblique bridge of small width. Fig. 5 is a half-section; fig. 4 is a half elevation; fig. 6 a plan above the foundations; and fig. 7 is a half-section taken on the square.

A bridge over a cutting may be built without a centre: one was built thus on the Birmingham and Gloucester Railway. The abutments being built up to the height of the springing, the earth was cut away to the form of the arch; seven rows of pegs were then inserted, showing the proper curve; a line of 3-inch planks was laid across, and on them were laid battens on edge, gauged to the exact profile; the earth was consolidated, and a batten flooring laid over it. This bridge was constructed of small pieces of limestone.

SECTION III.—WOODEN BRIDGES.

Wood was undoubtedly the first material ever used in the construction of bridges, the most ancient of which consisted simply of a rough log or tree thrown across a narrow stream or chasm. After a time these logs were squared, and either laid from one side to the other, or, where the width was greater, supported on some kind of trestle. This afterwards gave place to timbers or girders trussed in various ways. In the present day wood is chiefly used where it is very plentiful, and economy is the main object, as is generally the case in the United States of America.

The modes of constructing wooden bridges are extremely varied. One of the worst is that in which the timbers are short, and abutting against one another in the form of a curb or Mansard roof; and the best are constructed of curved ribs of different forms according to the span.

te V. figs. 4, 5

For small spans of less than 40 feet, with a rise of $\frac{1}{8}$th, the ribs may be formed by taking five or six pieces of 3-inch plank, 9 inches deep, abutting against each other, with other pieces, 12 inches deep, crossing the joints of the first, and keyed to them

with wooden keys. Two of these ribs with joists across will support an ordinary roadway.

Plate IV. figs. 3, 4, 5.

For arches of 200 feet span, the ribs should consist of pieces of scantling bent to the proper curve by steaming or otherwise. In figs. 3, 4, 5, the arch is composed of four ribs, each 18 inches thick and 4 feet deep, having two thicknesses in width and three or four in depth, according to the size of the scantling to be obtained. The joints are well scarfed, bolted, and keyed; and the vertical supporting pieces are notched on to the ribs in pairs, bolted together like suspenders, and placed from 15 to 18 feet apart.

A cross tie is bolted to each side of the vertical pieces, and notched on to the ribs, both on the upper and under side.

Between the timbers carrying the roadway joists, diagonal braces should be framed to prevent lateral motion.

In stormy positions, or where very heavy loads are likely to pass, braces may also be framed with advantage here and there over the back of the ribs, which should not be more than 8 feet apart.

Plate IV. figs. 1, 2.

For a still larger span, from 250 to 400 feet, it is best to construct frames each consisting of two ribs curved as in the last example. Radial pieces are notched on to the ribs like the vertical pieces in the last, and between these are crosses halved together in the middle, and abutting end to end between the radials.

The vertical roadway supports are connected with the radials, and at A B horizontal ties are notched and bolted to them to stiffen the work; for the same purpose diagonal braces may be applied on the horizontal cross ties and also between the roadway bearers, and other braces may be framed in a few places between the rib-frames, as shown by dotted lines.

To form the roadway, joists are laid across the bearers, and covered with 3 or 4-inch plank, and on this gravel is laid, either by itself or paved with blocks of stone. It should be about 18 inches thick in the middle, and 14 at the sides of the road, and means must be adopted for carrying off the wet.

As, however, the wet will soak through the paving or gravel, and injure the planking, some have only used a wooden roadway, laying a second tier of plank crossing the former one. This might, however, be avoided by covering the plank with some kind of asphalt, impervious to the rain.

If practicable, stone should be used for the abutments and piers; but if wood is preferred, the best mode is to drive piles about 2 feet apart in the direction of the current, and to strengthen them by diagonal braces. When the water is deep, the piles should be cut just below low-water mark, and posts morticed into them and secured by bolts and straps. The latter method has this advantage, that thus the part below water, which does not decay so quickly, is separated from the upper part, which, being alternately wet and dry, is very perishable, and requires frequent repairs, and can by this arrangement be easily renewed.

Tredgold gives the following rules. To find the thickness of abutment necessary to resist the thrust of a timber arch,—take h = height of abutment; w = weight of a square foot of the arch; s = half the span; and R = the rise; then,

$$\frac{\left\{\sqrt{\left(\frac{160\,h^2}{w\,\mathrm{R}}+1\right)}-1\right\}s\,w}{120\,h} = \text{the thickness required.}$$

This is about one-fourth more than is absolutely necessary to resist the thrust, in addition to the weight of that part of the abutment above the springing.

To calculate the scantling of the arch-ribs, put w = width of bridge; s = half the span; R = the rise; and n = the number of ribs; then

$$\frac{w \times s^2}{\mathrm{R}\, n} \times 0\cdot 0011 = \text{the area of the rib in feet when gravelled.}$$

When only planked, take 0·0007 for a multiplier instead of 0·0011. This will be enough to bear the weight of the roadway alone, but $\frac{1}{5}$th more should be added, to allow for the additional strain occasioned by the passage of heavy waggons or other causes.

The rise of a wooden arch must not be less than that given by the equation

$$\frac{s^2}{2\sqrt{h^2 - s^2}} = \text{the rise};$$

where s = half the span, and h = the height of a column producing the same pressure on its base, as the greatest pressure that ought to be on the framing.

The following Table gives the least rise which may be given to different spans. A small rise requires a greater amount of material to give the same strength as a greater rise.

Span.	Rise.	Span.	Rise.	Span.	Rise.
30	0·5	120	7	280	24
40	0·8	140	8	300	28
50	1·4	160	10	320	32
60	2	180	11	350	39
70	2·5	200	12	380	47
80	3	220	14	400	53
90	4	240	17		
100	5	260	20		

The settlement of wooden arches is given by Wiebeking as $\frac{1}{72}$; that is, a bridge of 144 feet span and 1 foot rise will become horizontal, and consequently for a final ascent of $\frac{1}{24}$ it must be framed to $\frac{1}{18}$.

Plate V. figs. 2, 3. Figs. 2, 3, Plate V., show some of the modes of supporting wooden bridges, where the timbers are short and piers form no obstacle to the navigation.

Fig. 9 shows the form of a wooden pier.

Plate V. fig. 1. Suspended roadway. Fig. 1 is a form frequently adopted in America for bridges of great extent and with low abutments. The width of the bridge is divided by arches rising above the roadway, and to these are suspended verticals, either of wood or iron, which support the sleepers or girders on which the roadway is carried: the ends of the arcs are usually notched into the girders. Stevenson describes one of these bridges over the

Susquehanna Bridge. Susquehanna at Columbia. "It consists of twenty-nine arches of 200 feet span; supported on two abutments and twenty-eight piers of masonry. The waterway is 5800 feet, and the whole length, including abutments and piers, about $1\frac{1}{4}$ mile. It is supported by three wooden arcs, forming a double roadway. There are also two footpaths, making the whole breadth 30 feet. The arcs are formed of two pieces, each 7 inches wide by 14 deep, placed 9 inches apart; the beams by which the roadway is suspended being placed between them, and fixed by iron bolts passing through the whole."

Plate V. figs 7, 8. Prussian arch. There is another kind of wooden arch employed in Prussia, composed of a beam with three or five saw-kerfs, by means of which it is bent to the required curve.

Fig. 6. The mode of bending is described by Colonel Nelson in vol. iii. of Professional Papers, as follows. "In this figure only three kerfs are shown; it is more usual and advisable

to have five. The centre kerf is first cut, reaching from the butt along $\frac{3}{4}$ths or $\frac{4}{5}$ths of the length; the saw is then returned on each side to complete the other two kerfs, which stop at 2 or 3 feet short of the butt. When five kerfs are made, the last two commence at L and end at G.

"The beam thus prepared is laid on the horizontal frame A B C, in the position I J.

"A B C is a frame of rough spars, halved into each other, and firmly picketed or otherwise fixed at the angles; E E′, any convenient number of smaller spars radiating from B, and halved into or otherwise secured to A C and D F; $c\,c'\,c''\,c'''$ cleats spiked down at points giving the intended curve.

"In bending the beam, the first thing to be done is to fix the butt very firmly at G, by means of pickets, double cleats c c, lashing, &c. Any convenient power, such as crab, block and tackle, &c., is then applied in a direction about parallel to E′ B; the rope or chain is fixed to H, and the beam is very gradually pulled down to the cleats c', c'', c''', in succession. As soon as the desired curve is obtained, the cleat b on B C is spiked down, and the beam lashed to the principal spars of the frame. The mortise I is next cut, and a tongue of wood harder than the beam is driven in. Lastly, the beam is hooped, at intervals of perhaps 2 feet, with iron collars, each closed with screw and nut, or with bolt and rivet. In ordinary cases these hoops should be of, say 2 in. $\times$ $\frac{1}{4}$ or $\frac{3}{8}$-inch flat iron.

"The beam thus hooped and mortised at I (which is an important part of the process) may be taken from the frame at once, without any fear of its altering its form.

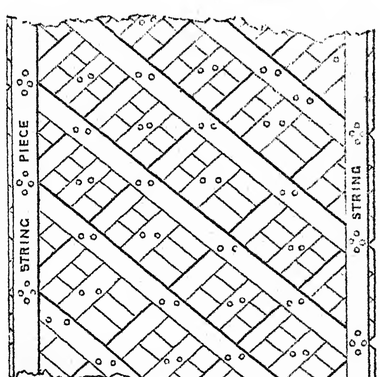
"The cleats $c'\,c''\,c'''$ can be fixed permanently to the spars E, and these last placed and secured according to circumstances. N.B. The natural tapering of the wood is always preserved, squared as baulk."

Plate V. fig. 10. Fig. 10 shows the form of Love's trussed girder, which may be applied to bridges, and a modification of which, constructed of iron, might be advantageously employed for the road bearers of suspension bridges, as recommended by the writer in the section on those structures.

Town's lattice. There is still another kind of bridge much used in America, viz. Town's patent lattice, consisting of a series of braces, inclined at rather more than 45°, with others crossing at the same angle, with a horizontal spring-piece bolted on each side at top and bottom. The whole of the bolts are made of hard wood. The height of the truss is usually $\frac{1}{10}$th or $\frac{1}{12}$th of the span. The roadway may be either at top or bottom.

Fig. 5.

Elevation.



Plan.

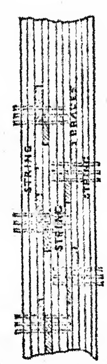


Plate V. figs. 11, 12. Figs. 11, 12, show the form of an ice-breaker to be used in rivers subject to floating ice: it should be moored a short distance above the bridge, with the sharp point up stream.

SECTION IV.—IRON BRIDGES.

The principles of the construction of iron bridges are in many respects similar to those of wooden ones; that is, they are composed of several ribs kept in position and strengthened by distance pieces, diagonal braces, &c.; and on these ribs are placed spandril standards supporting the roadway bearers.

In small arches the spandril standards and the ribs may be cast together.

In some cases the ribs have been formed by crossing the joints of short plates of different widths, like the planks in wooden arches of small span; but usually the parts of the rib abut end to end, and are connected by flanges bolted firmly together.

The ends of the ribs are fixed to abutment plates bedded in the masonry skew backs.

The abutments and piers may be either constructed entirely of masonry, or else of masonry as high as the springing, and iron above. The masonry of the piers might be entirely dispensed with, and iron piles substituted, if some means were found by which they could be rendered incorrodible, which object may perhaps be attained by the process of galvanism, as lately applied to that purpose. Iron has, however, this disadvantage, that if one of the piles were struck by a heavy body, it would probably break and cause great danger to the superstructure.

Plates VI. & VII. Plates VI. and VII. represent the bridge erected by Telford over the Severn at Tewkesbury.

The arch is 170 feet span, 17 feet rise, and the roadway 24 feet in the clear, between the rail skirtings.

The foundations of the abutments are supported on piles with sills spiked down to them, and the interior spaces filled in with rubble stone well rammed and grouted. From the springing-course up to the roadway, the structure consists of six arches with piers and pilasters,—the piers of masonry, the pilasters of iron.

The great arch is composed of six ribs laid at equal distances and placed on strong abutment plates, firmly bedded in masonry. These are secured in their places by gauge-pipes and connecting wrought-iron bolts, covered with grated plates fastened by mortises fitted to joggles in the main ribs, and by screwed flanges. On these the spandril standard crosses are placed, and secured by gauge-pipes and cross ties in the middle, and tenons at top and bottom. On the top of these are the road bearers, one over each rib, and on them the road plates are secured.

Plate VI. Plate VI. Fig. 1 is an elevation of half the bridge.

Fig. 2 is a plan of one of the abutments.

Fig. 3 is a plan of the platform of the abutment.

Fig. 4 is a section through the abutment and one of the land arches.

Plate VII. Plate VII. Fig. 1 is an elevation of the main rib, showing the spandril crosses and skirting, railing, &c.

Fig. 2 is a plate for connecting the main ribs.

Fig. 3 shows the mode of connecting the pieces of the main ribs together. The rib flanges are 4 inches deep.

Fig. 4 is a section of one of the spandril crosses, taken at the middle. They are connected by wrought-iron bolts, and kept apart by gauge-pipes.

Fig. 5 shows one of the main balusters.

Fig. 6 is a section of the hand-rail.

Fig. 7 shows the skirting.

Fig. 8 shows the road plates, $\frac{7}{8}$ inch thick, with flanges 3 inches high inside.

Fig. 9 is a section of the diagonal braces, $5\frac{1}{2}$ inches square in the middle, 4 inches at the ends.

Fig. 10 shows the manner of connecting the road bearers with the abutments. They are in four lengths on each side of the crown.

Fig. 11 gives a plan and section of the springing-plate.

Fig. 12 shows the form of the plates for connecting the top of the main ribs. Flanges stand up three inches inside.

Fig. 13 shows a cast iron column.

The bridge erected on the Midland Counties Railway, over the Trent, near Sawley, is remarkable for its simplicity and the small number of its component parts.

It consists of three arches of 100 feet span, 10 feet rise, and 30 feet width. The piers are of masonry up to the springing, with iron standards above.

There are six ribs laid at equal distances, with diagonal braces and distance-pieces between, bolted to fillets on the sides of the ribs. Each rib is cast in three pieces, comprehending the spandril standards and roadway bearers: a platform of half-baulks is laid on the bearers, with longitudinal pieces of oak for the rails. The iron standards are connected to the ribs by lap-joints with screw-bolts.

The piers are 14 feet thick at bottom and 10 feet at top.

The abutments are 12 feet thick, backed by a land arch, and the wing walls are about 3 feet 9 inches thick on an average, and extend 54 feet.

SECTION V.—DRAWBRIDGES, INCLUDING BASCULE, SWIVEL, ROLLER, AND OTHERS.

The object of every kind of drawbridge is to obtain a firm and secure means of communication across a river, canal, or ditch, with the means of cutting off that communication when necessary,—for the purpose usually, in the two former instances, of permitting the passage of vessels of too great size to go under,—and in the latter case, to prevent an enemy crossing the ditch and gaining an entrance into the place fortified.

They are generally of three kinds, viz. the Bascule, Balance or Lifting; the Turning or Swivel; and the Roller Bridge.

Bascule or Balance.

The Balance Bridge.—This is the old form of drawbridge, as found in most of the ancient castles and fortifications, in many of which it is simply a platform turning on a pivot or hinge in the escarp wall, and raised by means of chains attached to the end of the bridge and passing over pulleys above the entrance.

When across a canal or river, the bridge is usually composed of two leaves meeting, in the middle when down, each of which turns vertically on a horizontal pivot fixed in the masonry or timber at the sides, a well-hole being sunk for the purpose of allowing the descent of the counterpoise attached to the tail of the bridge.

The following description is from the 1st volume of the 'Transactions of the Institution of Civil Engineers:'

Plate VIII. fig. 4.

"The bridge consists of eight cast-iron ribs, 9 inches deep at the centre or meeting by $1\frac{1}{2}$ inch thick in the plain part, and 2 or 3 at the edges, connected together by two sets of crosses to each leaf, the lowest close to the abutment, by hollow pipes and bolts nearer the middle, and by the meeting plates, which fit together with a tongue and groove. When the bridge is down, the under side or soffit of the ribs forms an arch of 36 feet 6 inches span and 3 feet 6 inches rise, resting on cast-iron abutment plates fixed in the masonry at the sides. From near the axis the ribs curve down below the fixed part of the bridge, and terminate in boxes of Kentlidge by way of counterpoise,

each box being attached to two ribs. The axis on which the bridge turns is 9 inches square, with fine turned bearings working in plummer-blocks bedded in the stonework, the centre being 5 feet 3 inches from the side of the lock. The fixed part of the bridge is supported by iron joists resting on the division walls of the pits for the counterpoise.—The bridge is lifted by four crabs, two on each side; the handle is applied to a 6-inch pinion, working into a spur-wheel 4 feet diameter, having on its axis a 12-inch pinion, working into a toothed segment, 5 feet 9 inches radius, fixed to the outer ribs of the bridge." To render the bridge nearly on an equipoise in all positions, two chains are hooked on to the tail, and these, passing over two pulleys in the wall, are attached to a chain of heavy flexible links hanging into the bridge-pit. "When the bridge is up, this chain tends by its weight to draw it down, and as the bridge descends, the chain falls on the bottom, forming a variable counterpoise. In raising the bridge, the reverse of this is the case. The bridge is about 100 tons in weight, and one leaf is usually opened or shut by three men in half a minute, but two *can* do it.—In comparing the balance with the swivel bridge, it may be observed that the former will work longer without adjustment, and bears more firmly on its abutments, but is more affected by the wind, costs more at the outset, and requires double the number of men to work it."

Swivel or Turning.

The swivel or turning bridge may also be formed in either one or two leaves. Each leaf turns horizontally on a pivot firmly fixed in the bank, on which it rests when open. Rollers are inserted beneath the end of the bridge, to make it move more freely.

The following is also from the 1st volume of the 'Transactions of the Institution of Civil Engineers:'

"Over this lock is a swivel bridge 12 feet 3 inches wide; it is 81 feet 9 inches long, and composed of two parts, which, meeting in the middle, form a segment of a circle. The bridge consists of six cast-iron ribs, about 2 inches thick in the plain part and $2\frac{1}{2}$ inches on the lower edge, connected together by cast-iron braces, and planked with $2\frac{1}{2}$-inch oak, covered with $1\frac{1}{2}$-inch fir. On each side of the lock, in the stone coping of a large brick pier, there is firmly imbedded a cast-iron circular plate, 11 feet 9 inches diameter by 6 inches wide, with a cross and pivot in the centre, also securely let into the masonry, and working in a socket under the bridge, with twenty conical rollers, 6 inches wide, by $10\frac{3}{4}$ inches diameter at one end, and $9\frac{3}{4}$ inches at the other, fitted in a frame, and revolving between the circular plate above mentioned and another similar one in the under side of the bridge. The ends or meeting parts of the bridge are not described from the centre pivot or axis of motion, but from a point on one side, whereby these parts, in shutting into a tongue and groove joint, do not come into actual contact till the bridge is shut, when it becomes completely fast, being wedged to the abutments on each side and kept in place by two keys at the meeting. The machinery consists of two 8-inch bevelled pinions, to one of which the handle is applied, and at the bottom of the vertical shaft of the other is fixed a 9-inch pinion, working into a spur-wheel, 4 feet diameter, on the axis of which is another pinion, 12 inches diameter, which turns the bridge by means of a toothed segment at the outer end. One man can open or shut either part of the bridge with ease in half a minute."

This kind of bridge is well adapted for positions where the abutments are low and there is a large horizontal space for working it. It does not appear to be well suited to the ditch of a fortification, for that reason.

Roller Bridges.

Of the bridges now in use, the one which appears best adapted to its object is the roller bridge, as invented by Mr. Le Sueur, of Jersey. These bridges are withdrawn by means of a pinion working in a rack on the under side of the platform, wit friction-rollers to render the work easier.

The following is from the 4th volume of Professional Papers:

Plate VIII. fig. 1. "This bridge cost £360. Plate VIII. fig. 1 shows a plan of the under side of the bridge; *a a* are oak beams 12 inches square; under these, iron rails, *b b*, are spiked, resting on rollers *g g* on the edge of the escarp; *c* is a rack bolted to the iron bearers *d d*, which also connect the whole framing; *e e* are trucks; and *f f* are friction-rollers, to ease the motion of the bridge. The hand-rail moves with the platform over rollers in the standards *p p*. When the bridge is withdrawn, the brow *x*, which moves on hinges, falls down over the opening in the escarp.

"Fig. 2 is a section through the ditch, and the bridge run out.

"Fig. 3 is an end view, showing the working machinery.

"The width of the ditch is 17 feet 6 inches, and the entire length of the bridge 32 feet 9 inches; the inner part being 14 feet 6 inches, on the end of which 400 lbs. of scrap iron are bolted as a counterpoise, to prevent the outer part from sinking. The width of the bridge is 9 feet 2 inches clear, and it is covered with 3-inch oak plank.

"In moving the bridge, the pinion *h* works in the rack *c*; the axis of this pinion is of $2\frac{1}{2}$-inch iron, and is carried into one of the bomb-proofs, where it carries a toothed wheel acted on by another pinion to which the handle is attached.

"The force of one man on this handle is enough to move the bridge.

"Its advantages are, that it does not obstruct the flanking fire of the place, and its withdrawal is entirely under command of men in the casemates. Its objections are, the length of time required to withdraw it, and the necessity for a level space in rear, the whole length of the bridge. The weight of the whole bridge is 6 tons 15 cwt. 3 qrs. 10 lbs. The whole might be advantageously made of cast iron."

Plate IX. fig. 1. There are two other kinds of drawbridges which have been adopted in Bermuda, as described in the 9th volume of Professional Papers. One of these is a balance bridge, in which, however, the outer end is lowered instead of being raised, as usual, to cut off the communication. When up, it is retained in its place by a long iron bolt, which would necessarily be subject to an immense strain during the passage of heavy weights, and consequently these bridges should only be used for foot passengers and other light traffic.

The other kind of bridge is on the suspension principle, and was invented by the late Colonel Blanshard. It is composed of several leaves joined together, and is supported by two chains on each side, passing through the suspending pieces, to which the leaves

Figs. 2 and 3. are attached. The upper chain on each side is fastened to the ground, 12 feet from the counterscarp, passes over a pillar 2 feet high and 1 foot from the edge of the counterscarp, and after crossing the ditch, is carried over a 6-inch sheave on the side of the opening in the escarp, on a level with the top of the counterscarp pillar, and thence round a windlass beneath the roadway, and 23 feet from the face of the escarp. The lower chain is fastened to a hook in the face of the counterscarp, and crossing the ditch, passes over a sheave below the other, and round a windlass placed 20 feet from the escarp.

In the 3rd volume of Professional Papers, page 189, Colonel Jebb has given a description of a drawbridge particularly applicable when it is necessary that the platform should be withdrawn to one side instead of along the straight line.

SECTION VI.—SUSPENSION BRIDGES.

Various opinions have been entertained as to the form best adapted for the objects of a suspension bridge. These objects are,—1st. The obtaining a roadway across a river in a position where t is necessary to allow the passage of vessels beneath it,

and where it is not possible to form piers or abutments sufficiently close together to allow of an ordinary arch being constructed. 2ndly. The judicious arrangement of the suspending chains, rods, and roadway bearers, to affect the greatest firmness and rigidity with the least expenditure of material.

The question does not yet appear to be fully settled, but the preference, in theory at least, seems to be given to Dredge's Taper Chain. The following are the heads under which the different forms may be arranged.

First. Those in which the planking of the roadway (except a small portion near the abutments) rests solely on the main suspending chains, as in Chinese bridges generally, and some in South America.

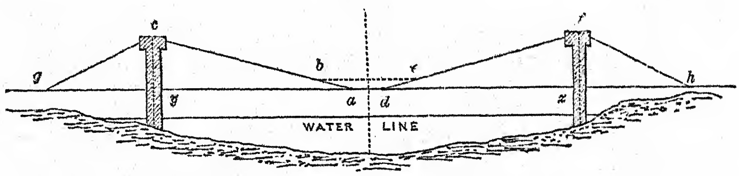
Second. Those in which the roadway side beams, carrying the planking, railing, &c., are only connected with the main suspending chains by vertical rods, as in the Menai Bridge, and numerous others.

Third. Those in which the roadway platform is entirely supported by ropes, chains, or wires proceeding obliquely from the top of the abutments, as in some bridges of rope, canes, or bamboos, in Asia, and light wire bridges in Europe. (A light rope bridge of this description may be seen in Plate XIV. under the head of 'Field Bridges,' in vol. i.)

Fourth. Those in which the roadway platform is partly supported by ropes or chains, or wires proceeding obliquely from the top of the abutments, partly by rods descending obliquely from the main chains, and partly by the main suspending chains themselves; which last, diminishing in weight as they approach the middle of the span, are linked to the central portion of the roadway by short rods, which, being nearly in continuation of the upper parts of the main chains, would, if strong enough, support that part of the roadway, and complete the curve, rendering the central link of the chain nearly unnecessary, as in Dredge's Bridge.

In this case it is necessary that the central portion of the roadway bearers should be made strong in proportion as the centre link *b e* (see annexed figure) of the main chain is weakened.

Fig. 6.



In all suspension bridges, chains are carried from the top of the abutments to the rear, and called back chains. There is one of these to each of the bridge chains, whether they carry the rods on each side, as in those of the second class, or go directly to the platform, as in the third and fourth classes. These back chains are connected with links secured on the top of cast-iron saddles on the abutments at one end, and firmly bolted to strong girders or blocks of masonry in the solid ground at the other.

In the case before us, the tension on the centre link will increase in an inverse ratio to the deflection of the chain. When *b a* becomes vertical, there is no tension on the roadway *a d*, but all on the link *b e*, and the tension on that portion of roadway will be greatest when the angle *b a y* is least; *i.e.* when *b a*, and *a d*, both become parts of the suspending chain. In this latter case strong holdfasts are necessary to prevent the roadway bending and the ends of the side-beams flying out from the abutments.

It seems best, however, to give the centre link sufficient strength to support the roadway in case of fracture of the side beams, which should also be made of great strength in the centre, to give rigidity to the structure.

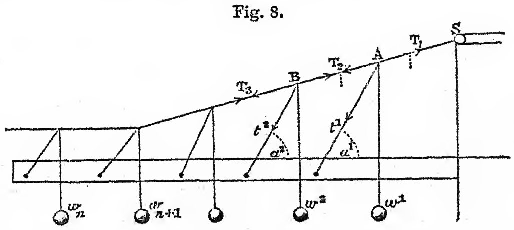
For this purpose it might be advisable, instead of adding breadth to the side roadway bearers, as proposed by Major Goodwyn in the Ballee Khâl Bridge, to give them additional depth, as in the annexed figure, and to increase the lateral strength of the platform by means of diagonal braces between the bearers.

Fig. 7.

The form of bridge described under the third head, having the road bearers entirely supported by chains descending from the piers without any rods, would be very good, but for the difficulty of equalising the tension in large spans. It is, however, well to have two or three besides the main chains descending from the piers direct, the chief objection to Dredge's Bridge being, that he carries the principle of tapering the chains too far, without rendering his side bearers strong enough to compensate.

The following formulæ are applicable to all cases of suspension bridges; the middle link being supposed horizontal, and the number of links $2n+1$.

Fig. 8.



In the above figure, let $w_1\, w_2 \ldots\ldots w_{n+1}$ be the weights of the links from either pier to the centre; $S_1\, S_2 \ldots\ldots S_w$ the weights of the suspending rods; $T_1\, T_2 \ldots\ldots T_{n+1}$ the tensions of the links, and $t_1\, t_2 \ldots\ldots t_n$ the suspending rods.

The two forces T_1 and T_1 support the weight of roadway links and rods, $= w$. Then $T_1 = \frac{1}{2}\, w.\ \operatorname{cosec} \beta_1$.

Also,

$$T_2 = \frac{\sin(\alpha_1 - \beta_1)}{\sin(\beta_1 - \beta_2)}\, t_1 + \tfrac{1}{2}(w_1 + w_2 + S_1) . \frac{\cos \beta_1}{\sin(\beta_1 - \beta_2)}$$

$$T_{n+1} = \frac{\sin(\alpha_n - \beta_n)}{\sin(\beta_n - \beta_{n+1})}\, t_n + \tfrac{1}{2}(w_n + w_{n+1} + S_n) . \frac{\cos \beta_n}{\sin(\beta_n - \beta_{n+1})}$$

for the tensions of the links.

The following are the tensions of the suspending rods:

$$t_1 = \frac{\sin(\beta_1 - \beta_2)}{\sin(\alpha_1 - \beta_2)}\, T_1 - \tfrac{1}{2}(w_1 + w_2 + S_1) . \frac{\cos \beta_2}{\sin(\alpha_1 - \beta_2)}$$

$$t_2 = \frac{\sin(\beta_2 - \beta_3)}{\sin(\beta_1 - \beta_2)} \cdot \frac{\sin(\alpha_1 - \beta_1)}{\sin(\alpha_2 - \beta_3)} \left\{ t_1 + \tfrac{1}{2}(w_1 + w_2 + S_1) . \frac{\cos \beta_1}{\sin(\alpha_1 - \beta_1)} \right\} - \tfrac{1}{2}(w_2 + w_3 + S_2)\, \frac{\cos \beta_3}{\sin(\alpha_2 - \beta_3)}$$

$$t_n = \frac{\sin(\beta_n - \beta_{n+1})}{\sin(\beta_{n+1} - \beta_n)} \cdot \frac{\sin(\alpha_{n-1} - \beta_{n-1})}{\sin(\alpha_n - \beta_{n+1})} \left\{ t_{n-1} + \tfrac{1}{2}(w_{n-1} + w_n + S_{n-1}) \right.$$

$$\left.\frac{\cos \beta_{n-1}}{\sin(\alpha_{n-1} - \beta_{n-1})}\right\} - \tfrac{1}{2}(w_n + w_{n+1} + S_n) \cdot \frac{\cos \beta_{n+1}}{\sin(\alpha_n - \beta_{n+1})}; \ (\beta_{n+1} = 0)$$

Plate X. Menai Bridge.

Plate X. represents the bridge erected by Telford over the Menai Straits. In this there are four chains on each side, one above the other, and the same number in two lines along the middle, the pathway being between. The rods are connected alternately to the first and third, and the second and fourth chains. They are placed 5 feet apart, and the centre span of the centre arch is, I think, 566 feet. Some years ago the violent action of a storm destroyed part of the roadway, but did not injure the chains. In this bridge the back chains support half-bays of the bridge.

Fig. 1 is an elevation of half the bridge.

Fig. 2 is a transverse section of the roadway, after the alterations executed by Mr. Provis, in consequence of the damage done by a severe storm in 1839. An additional row of planks was placed on the platform, and the footpaths were disconnected from the roadways, in order that, since thorough stiffness could not be given to a bridge in so exposed a position, the undulations occasioned by the wind might not cause the transverse bearers to break; and for the same reason an additional joint was formed in the suspension rods, just above the roadway. It is considered by some, that it is a great advantage to have a strongly trussed side railing to suspension bridges, to increase their stiffness longitudinally. The section of the chains gives 260 square inches of iron.

Plate XI.

Plate XI. represents the bridge erected by Major Goodwyn over the Ballee Khâl, near Calcutta, on a modification of the principles adopted by Mr. Dredge, the chains not being so much tapered, and the roadway being strengthened.

Fig. 1 is an elevation and section, showing the mode of securing the back chains.

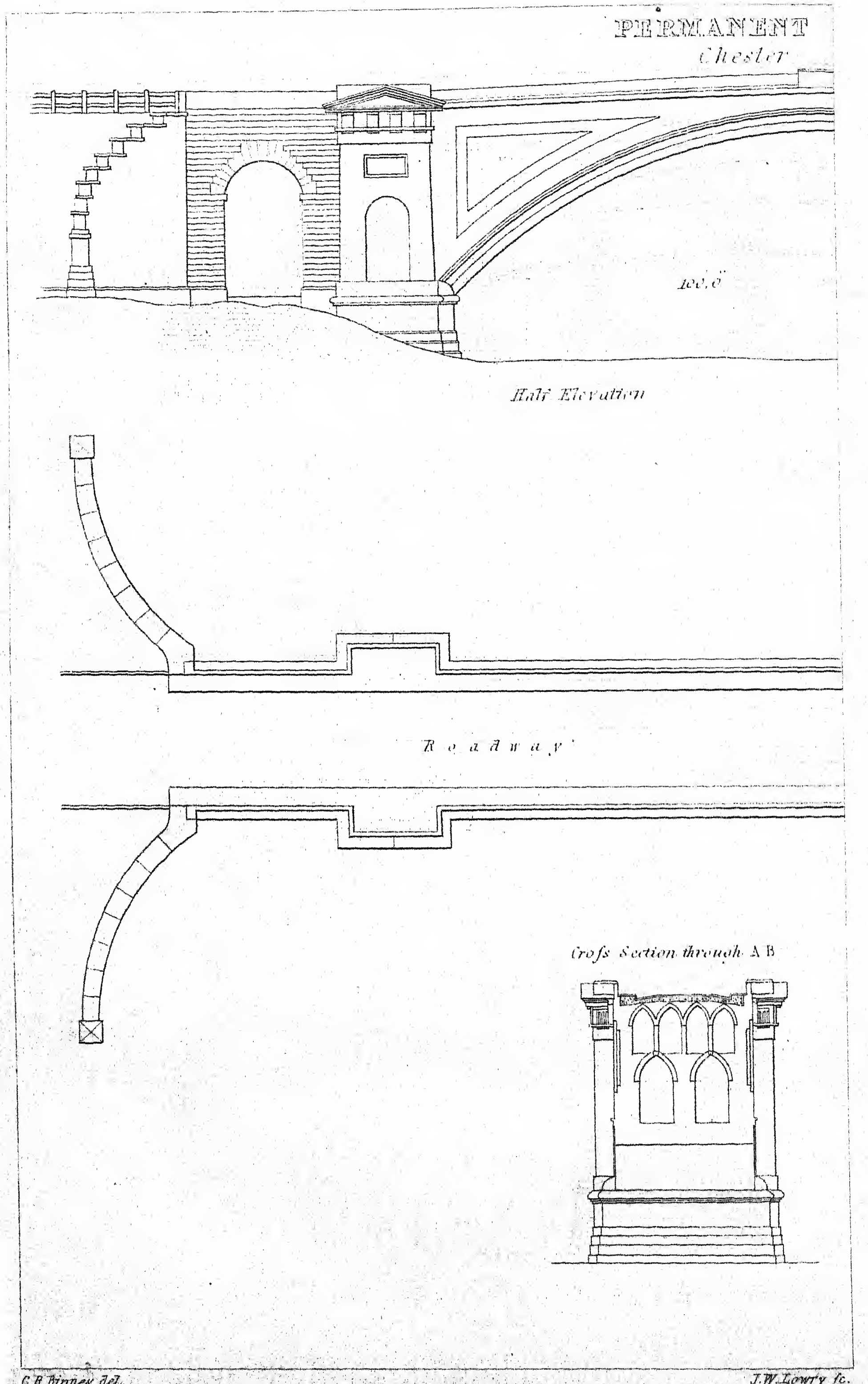
Fig. 2 is a plan of the chains and abutment.

SECTION VII.—IRON TUBULAR BRIDGES.

Some notice may naturally be expected of the wonderful structures which were erected shortly before and after the first edition of this article was published, viz., the Britannia and Conway Bridges on the Chester and Holyhead Railway, and the Albert or Saltash Bridge on the Cornwall Line. As however so much has been already written about them, a few words will suffice.

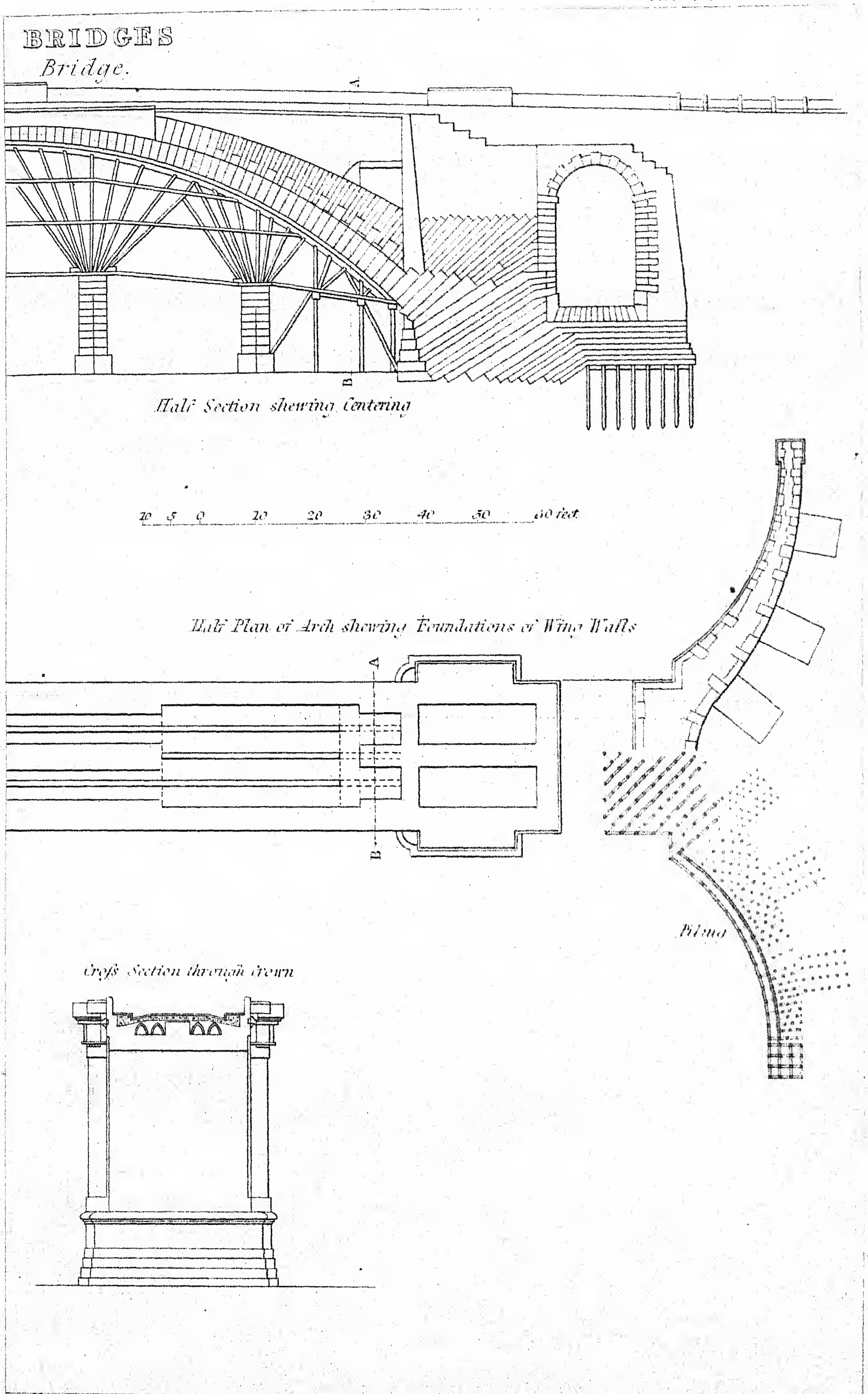
The Britannia Bridge carries the Railway across the Menai Straits from the county of Carnarvon to the Isle of Anglesea, a short distance to the south of Telford's Suspension Bridge already noticed. The total length of this bridge is about 1841 feet. The two lines of rails are carried separately, each inside of an immense iron tube, or rather a succession of tubes placed end to end and resting on masonry piers. The tubes are 26 feet high × 14 feet 6 inches wide on the outside; and 22 feet × 14 feet inside, the difference in the depth being caused by a row of small tubes or cells, formed along the top and bottom of the main tubes and strengthened by flanges and angle pieces. On these cells especially depends the strength of the tubes.

The span of each of the two centre openings is nearly 460 feet, and of the shore ends 230 feet, and the height of the underside of the tubes above high water more than 103 feet. All the tubes—the large ones being each 472 feet long and weighing 1600 tons—were raised by means of hydraulic pressure, a very small space at a time, up grooves previously left in the piers and built up solid underneath after each lift, before the pressure was removed; so as to prevent risk in the event of any portion of the hydraulic machinery giving way. In all bridges of this kind it is necessary to have an arrangement of rollers at each end of the tubes, which are left free, to allow of their expansion or contraction without injury to themselves or the piers.



G.R.Binney del. J.W.Lowry fc.

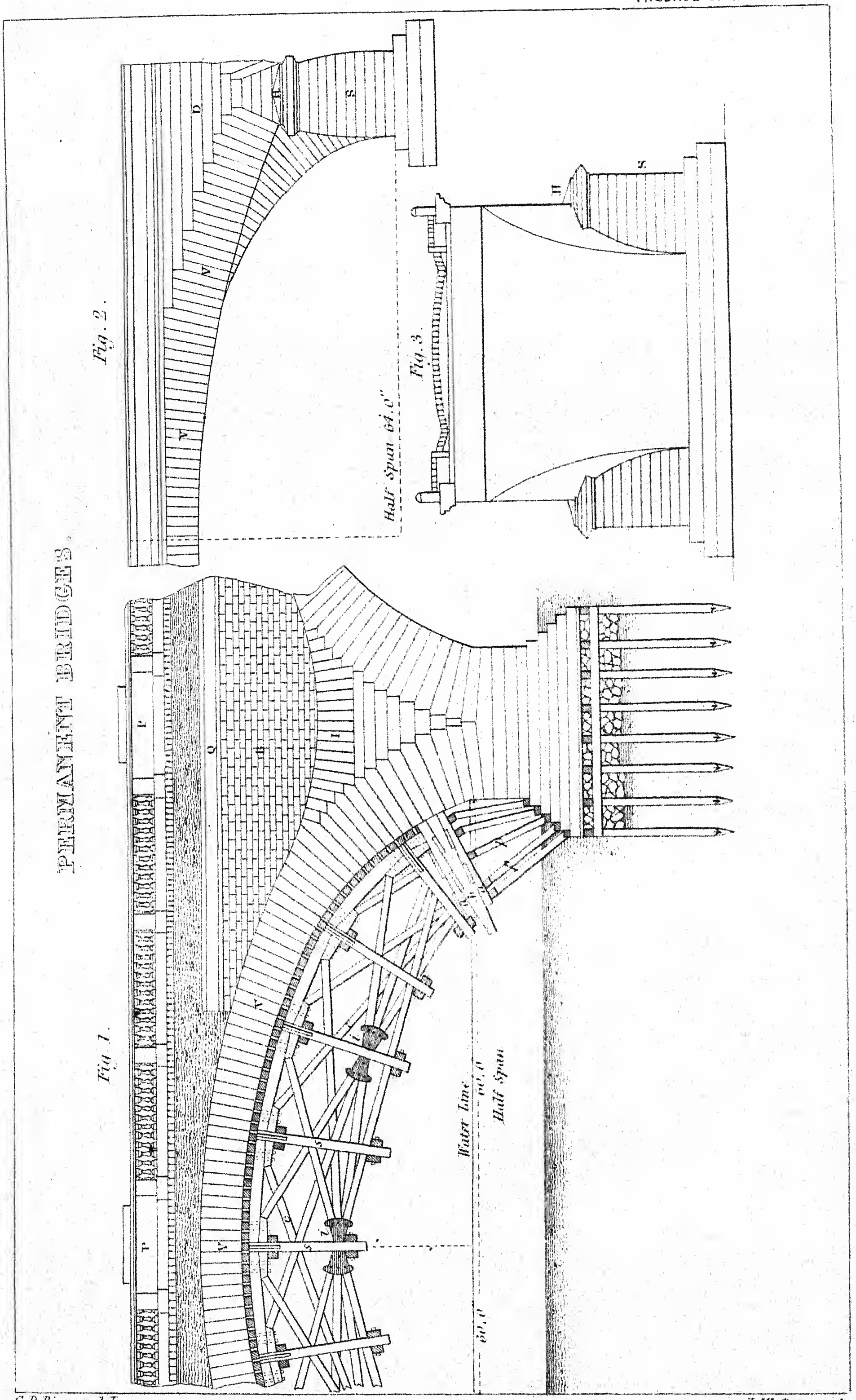
London: Lockwood & Co 7 Stationers' Hall Court, Ludgate Hill, 1861.



C.R.Binney del.

J.W. Lowry fc.

London: Lockwood & Co. 7 Stationers' Hall Court, Ludgate Hill, 1861.



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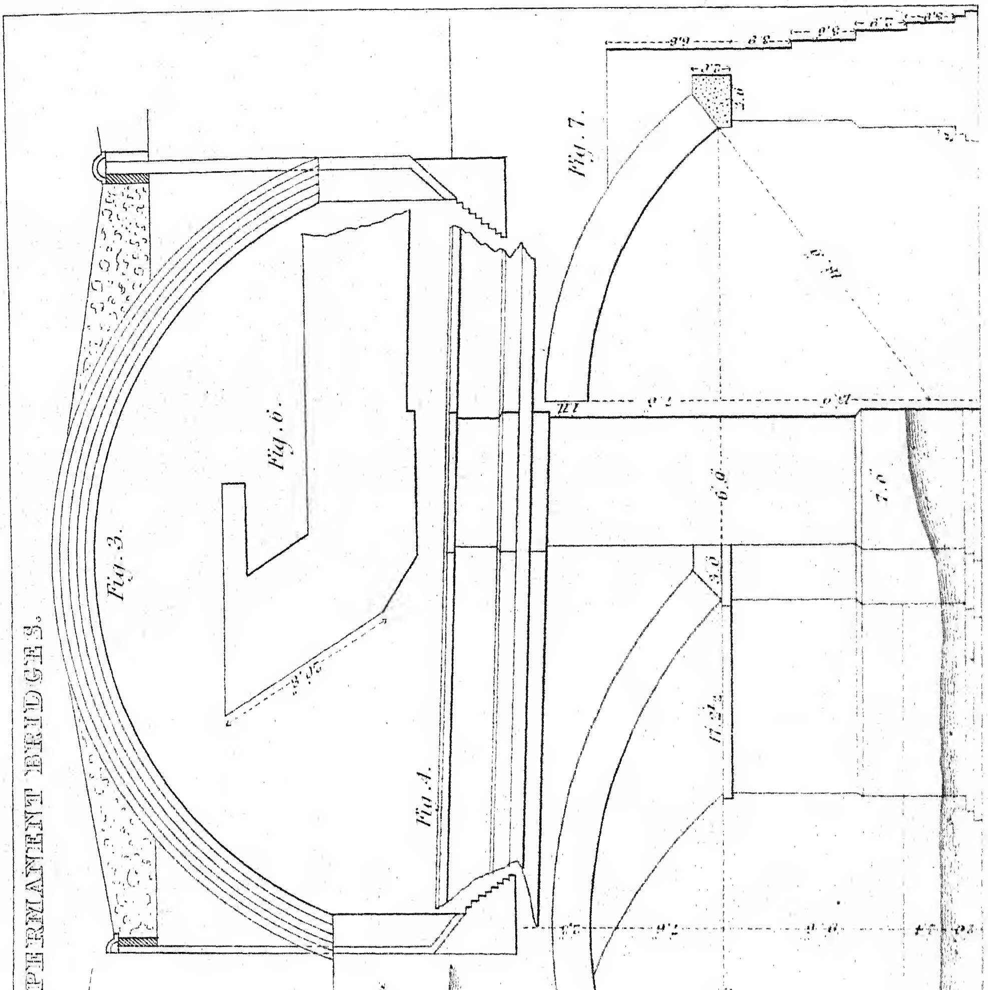
London: Lockwood & C°, 7 Stationers' Hall Court, Ludgate Hill; 1861.



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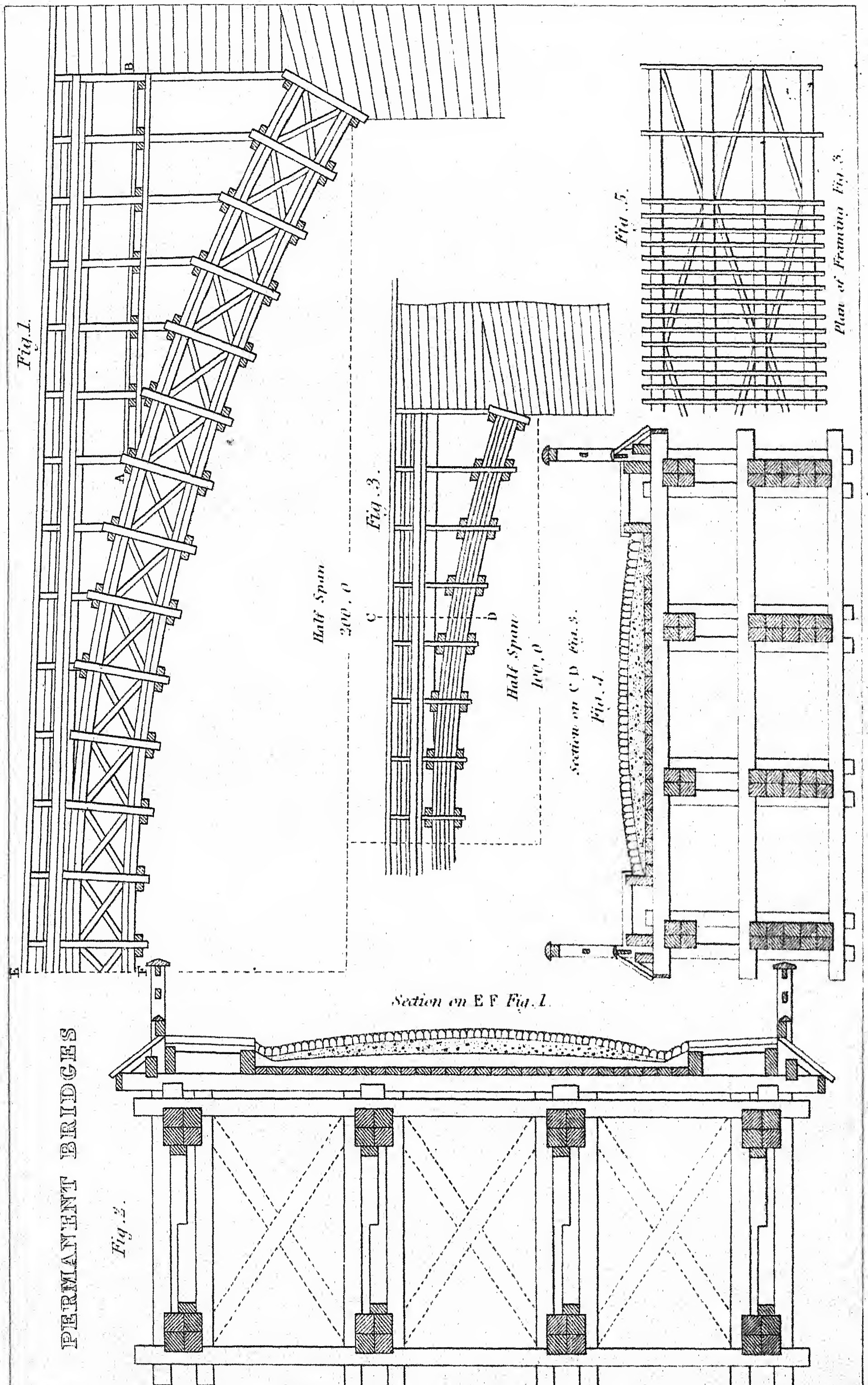

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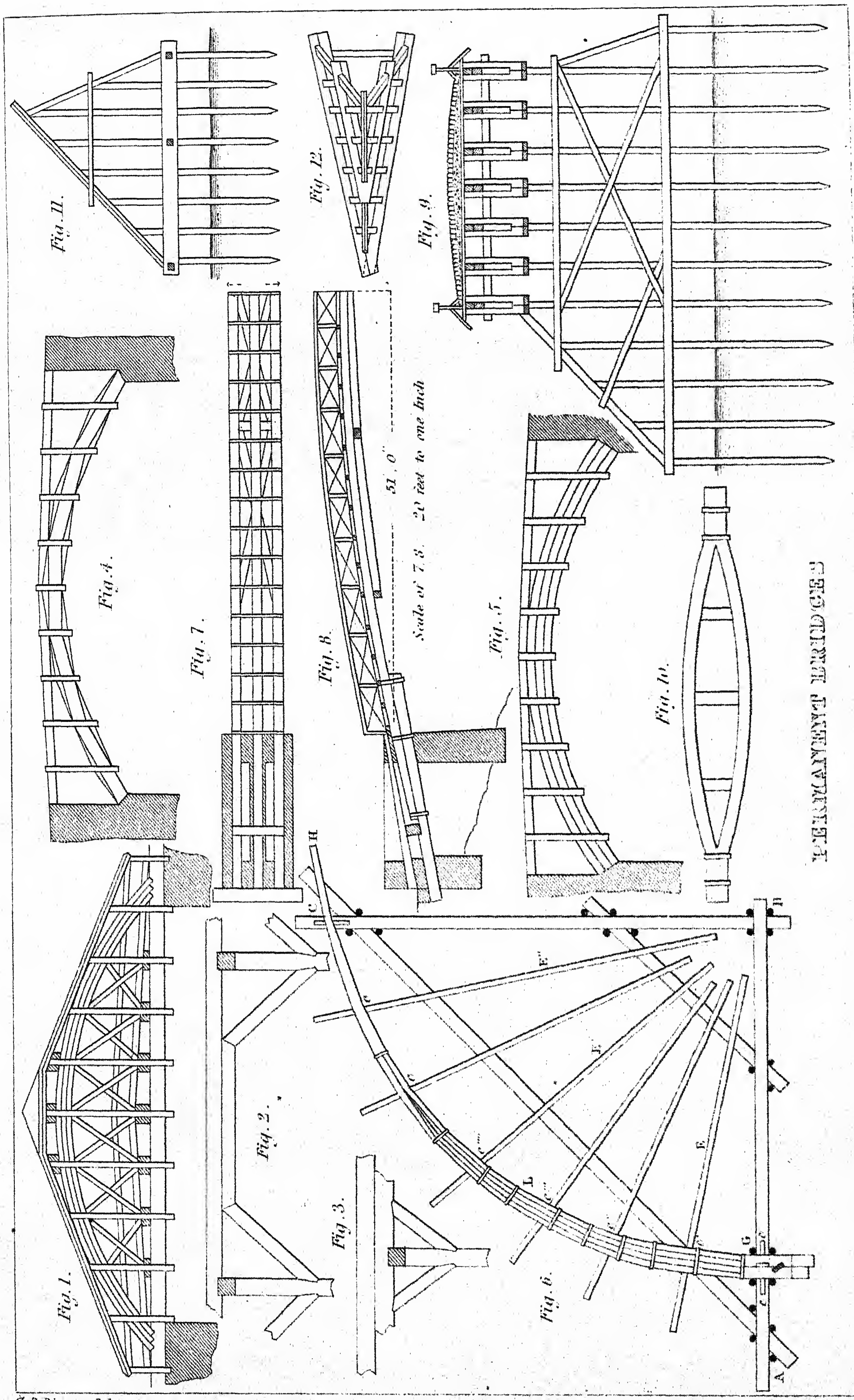

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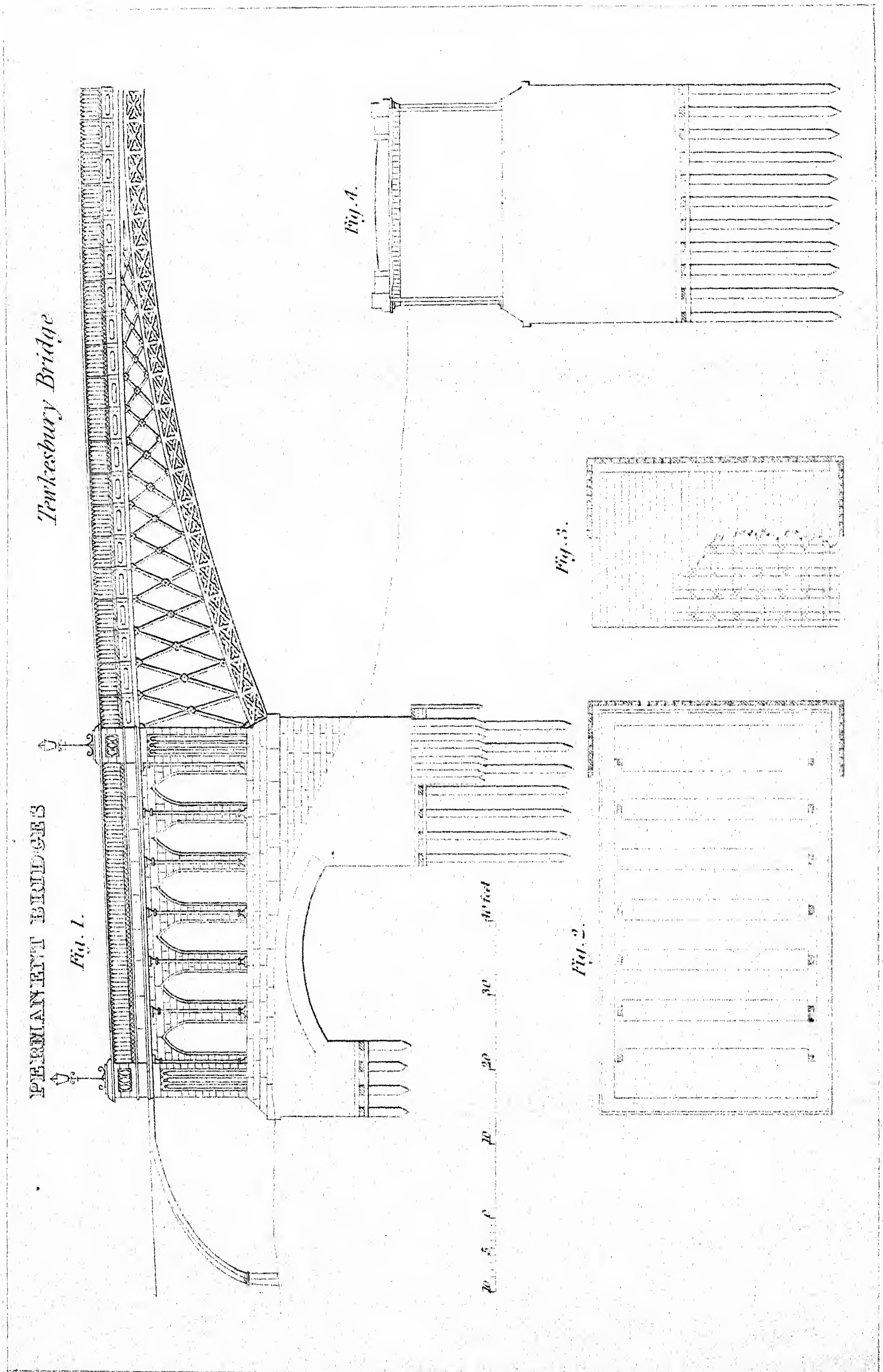
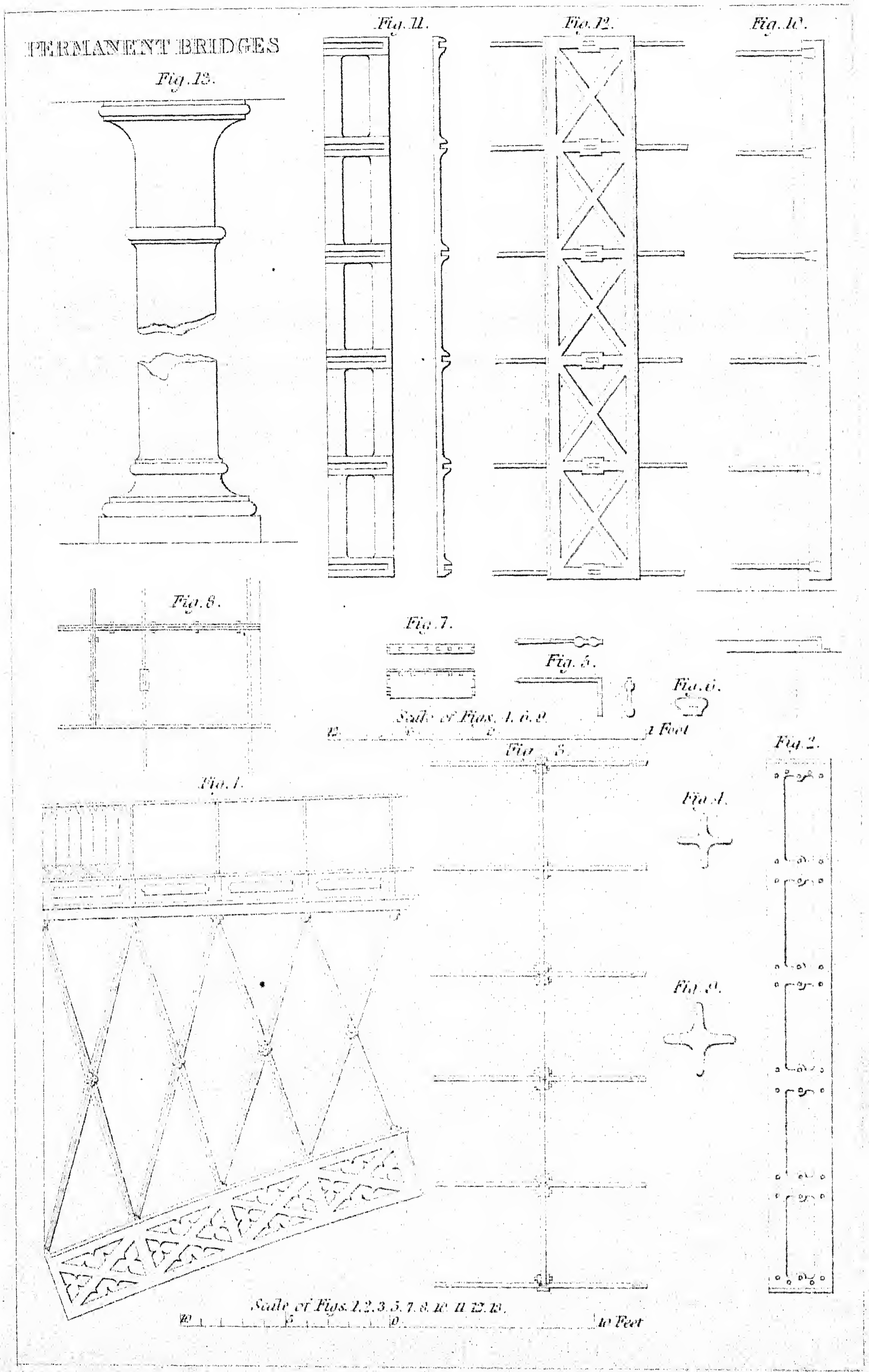


C. R. Binney del^t. J. W. Lowry fc.

London: Lockwood & C^o. 7 Stationers' Hall Court, Ludgate Hill, 1861.



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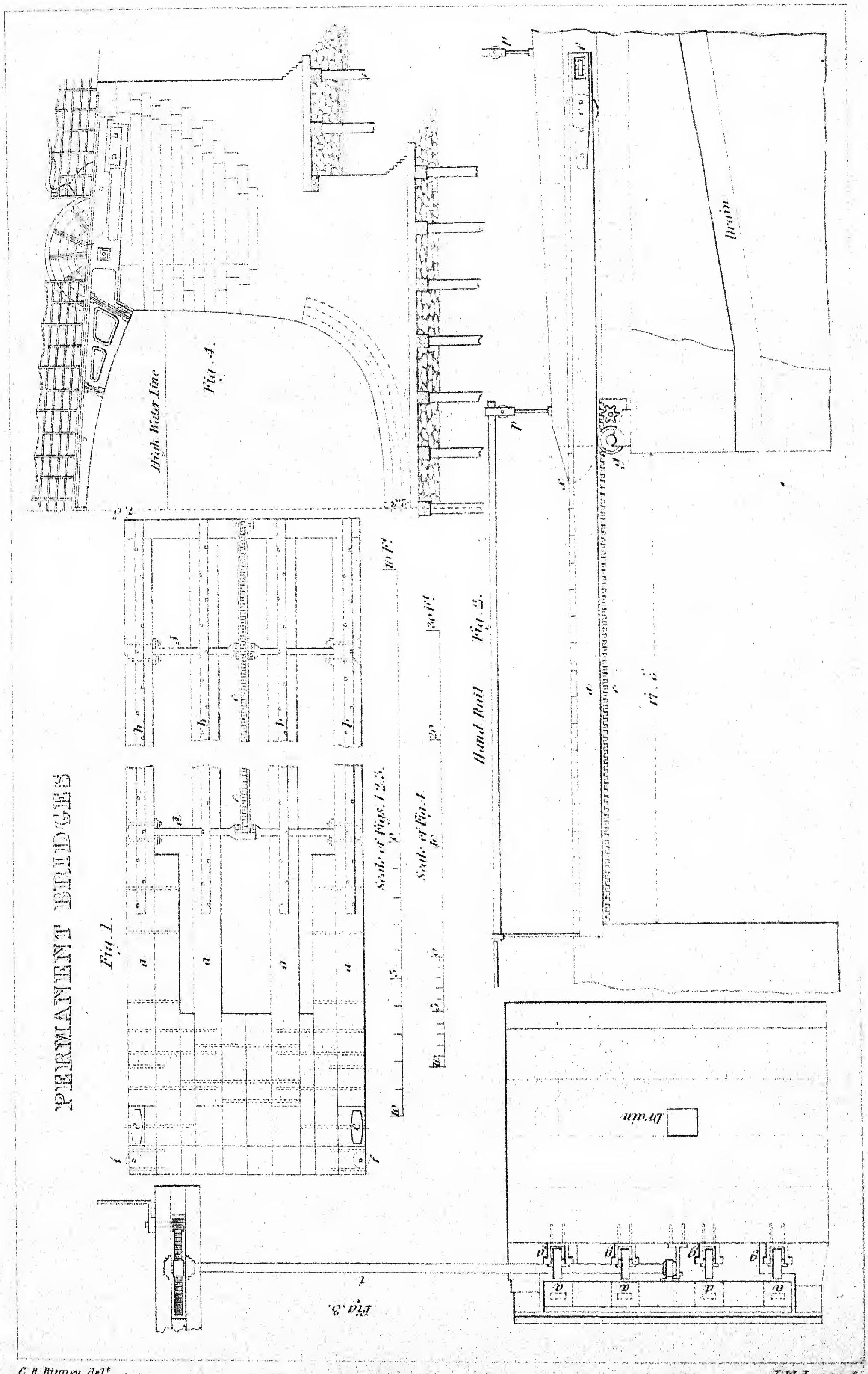
London: Lockwood & C.o 7 Stationers' Hall Court, Ludgate Hill; 1861.



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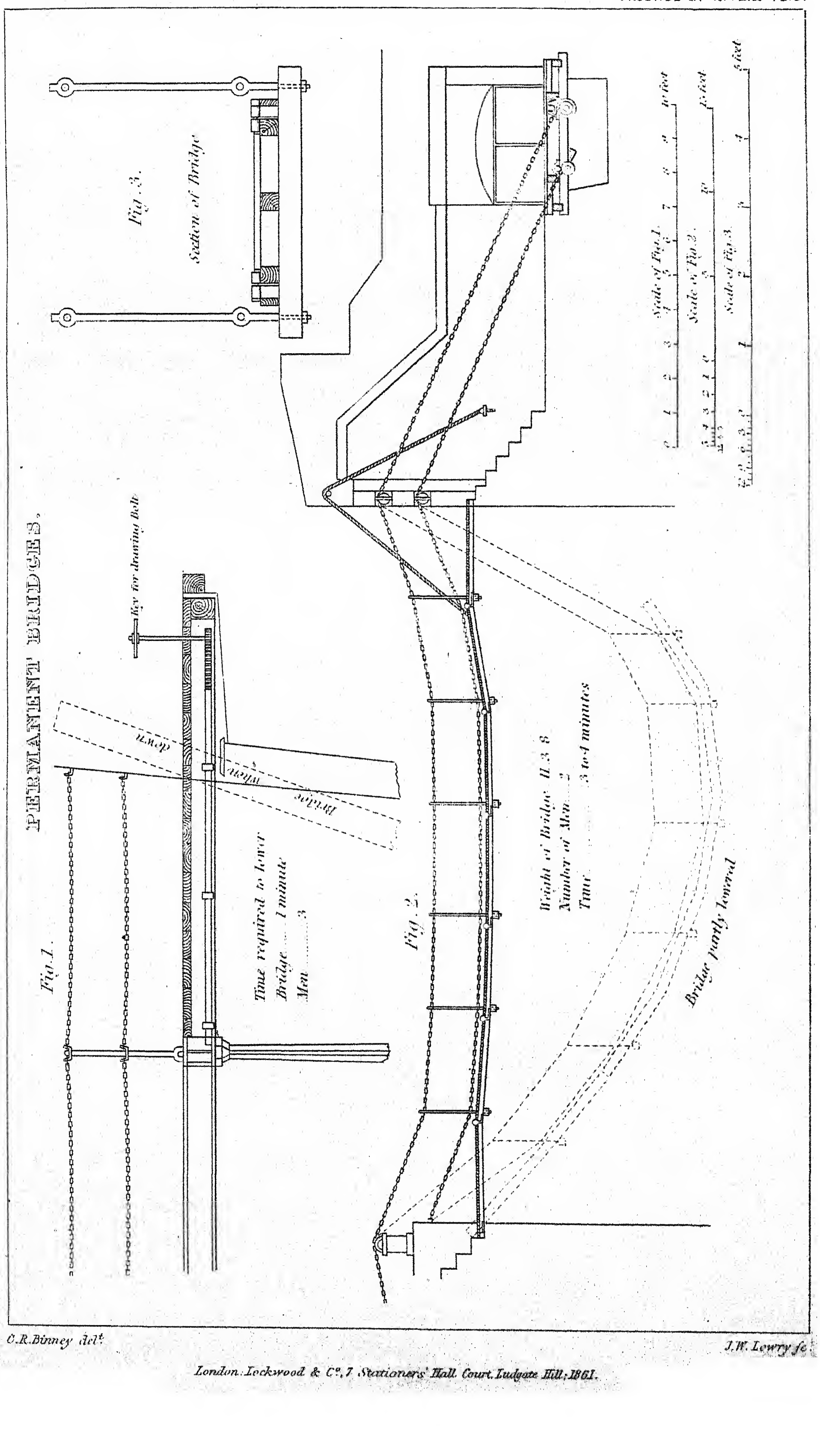

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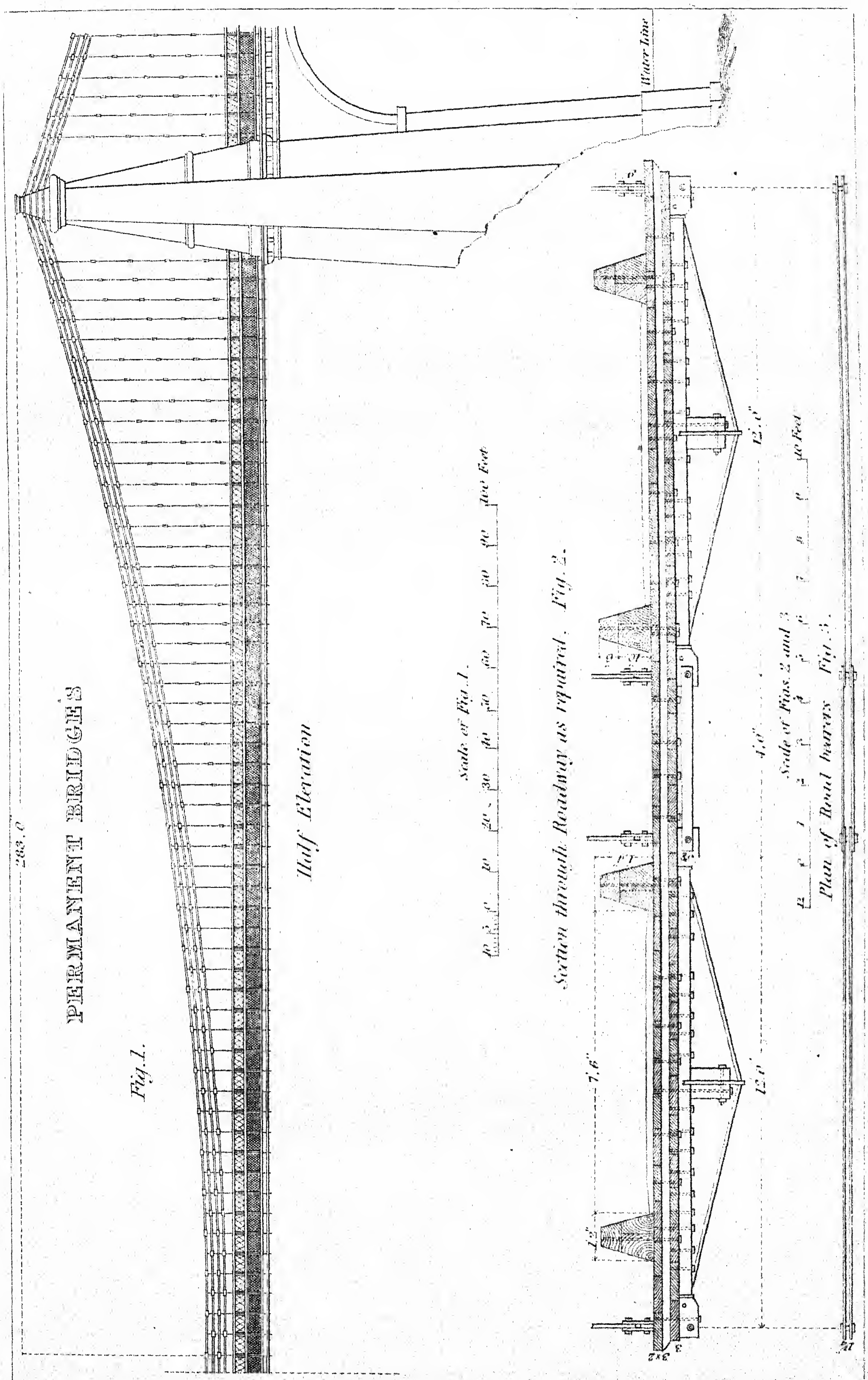
J.W. Lowry sc.

London: Lockwood & C^o. 7 Stationers' Hall Court, Ludgate Hill; 1861.



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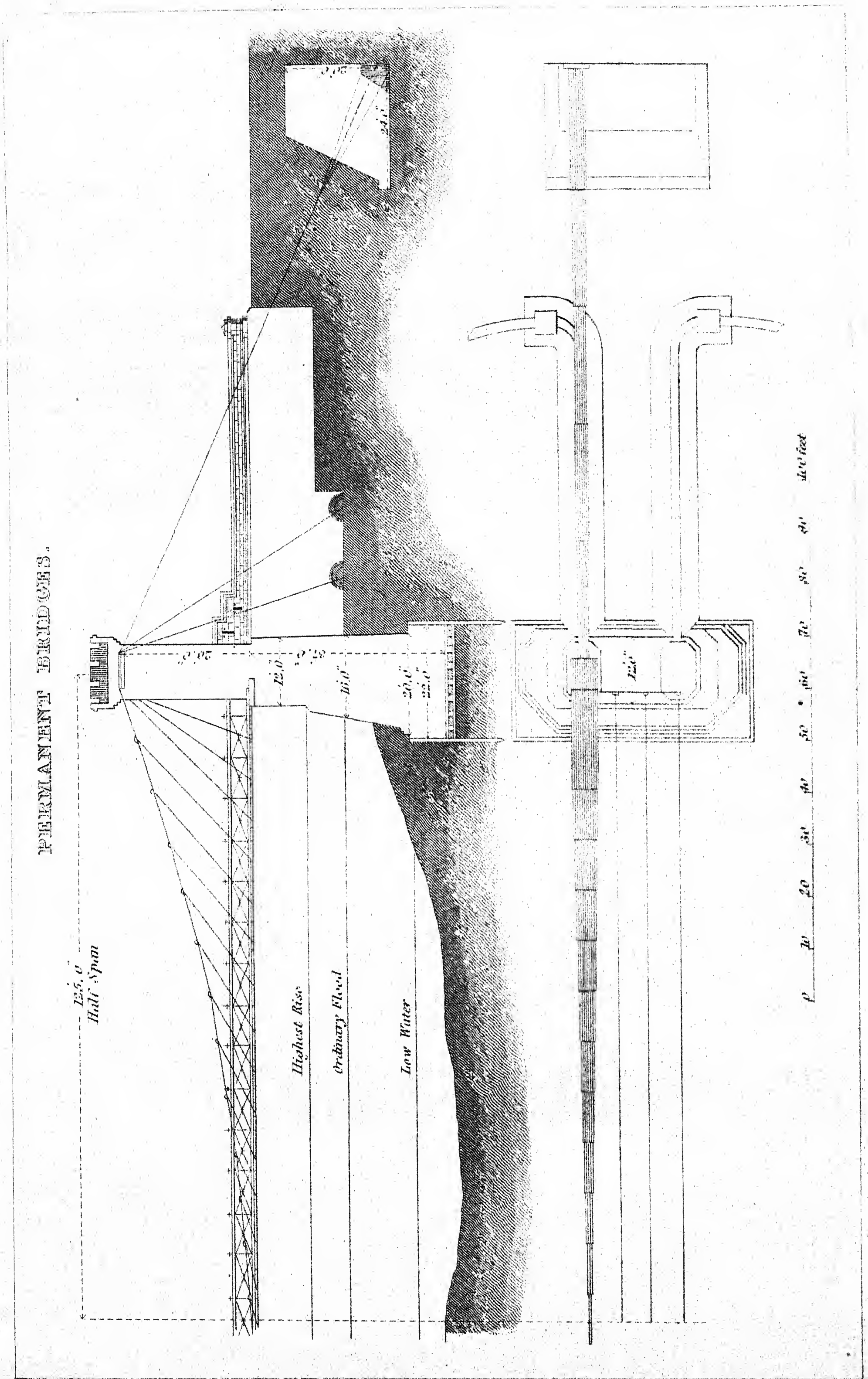


C.R.Binney del. J.W.Lowry fc.

London: Lockwood & Co. 7 Stationers' Hall Court, Ludgate Hill; 1861.

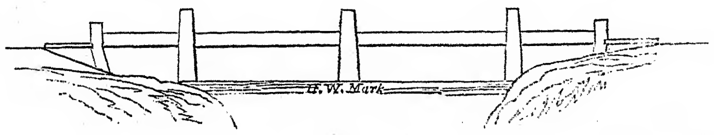
The Conway Bridge is of the same general construction, but consists of only one span of 400 feet clear, each tube weighing 1300 tons.

The Albert Bridge crosses from near St. Budeaux on the Devonshire, to Saltash on the Cornwall, side of the Tamar, near its mouth or junction with the Hamoaze. It carries only one line of rail and, unlike the Britannia or Conway, is open at the top, the sides being formed with cells as in the Liverpool and other landing piers, &c. The portion from the high ground to the water's edge is carried on a number of lofty masonry piers at moderate intervals, the part on the Saltash side being curved round in a direction nearly parallel to the water and at right angles to the previous direction of the bridge.

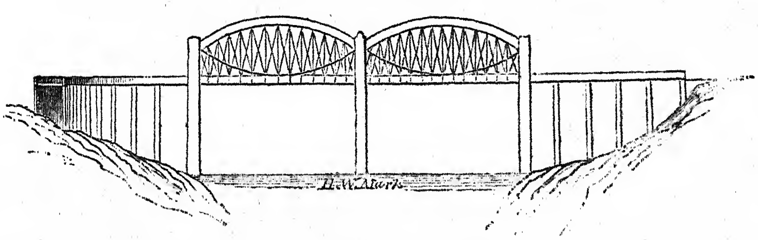
The part actually crossing the water consists of two spans of nearly 435 feet each, the under-side of the tubes being 100 feet above high water. The three piers supporting these long tubes are carried up in iron above the roadway, to a sufficient height to support suspension chains of the ordinary kind to which the roadway is attached. There are not any backchains, but from the top of the piers spring two enormous cylindrical tubular beams bent into the form of an arch, and carrying strong suspending rods braced together and also fastened to the roadway.

The following are rough diagrams of the Britannia and Albert Bridges.

Britannia Bridge.



Albert Bridge, Saltash.



The following works were consulted in the compilation of the above paper, viz.—'Transactions of the Institution of Civil Engineers,' 'Tredgold's Carpentry,' 'The Professional Papers of the Corps of Royal Engineers,' &c.

PENDULUM* [Latinè pendulum (*scil.* negotium), that which hangs down, dangles, from pendeo, I hang,] in Mechanics denotes any body so suspended that it is at liberty to vibrate or swing backwards and forwards, about a horizontal axis of suspension, by the action of gravity.

Pendulums receive different denominations according to the mode of their construction, or the purpose which they are intended to serve.

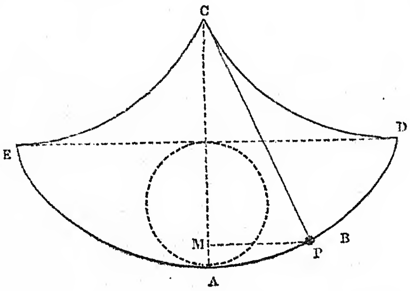
The *simple* pendulum is a mere theoretical abstraction, in which, for the purpose of

* By Mr. Heather, late of the Royal Military Academy, Woolwich.

more readily demonstrating the properties of this important machine, it is assumed that the whole weight of the suspended body is concentrated in a single point; that the cord by which it is suspended is without weight, of invariable length, and perfectly free from rigidity; that there is no friction at the axis of suspension, and no resistance to motion opposed by the atmosphere.

Properties of simple pendulums vibrating in cycloidal arcs.

It is a known property of the cycloid, that its evolute is a cycloid similar and equal to the former. If, then, a simple pendulum be suspended from C, the point of concurrence of two equal inverted semi-cycloidal cheeks, by a string of the proper length, and be made to vibrate between them, the heavy point P of the pendulum will describe an arc of an equal and similar cycloid D A E. The proper length of the suspending cord is twice the diameter of the generating circle. P then representing the position of the heavy point at any time t, let AM $= x$, MP $= y$, AP = the radius of the generating circle $= a$, and the length the suspending cord $= l$; then by the property of the curve $s = 2\sqrt{2\,a\,x}$; and therefore $s^2 = 8\,a\,x = 2l\,x$, since $l = 4\,a$. But, if ϕ be the angle which the tangent at P makes with the vertical, $\cos\phi = \frac{d\,x}{d\,s} = \frac{s}{l}$, and the force accelerating the body's motion in the direction of the curve is $g\cos\phi = \frac{g}{l}s$. The equation of motion therefore is $\frac{d^2 s}{d\,t^2} + \frac{g}{l}s = 0$, whence it appears that $s = \mathrm{A}\cos(t\sqrt{\frac{g}{l}} + \mathrm{C})$, and $\frac{d\,s}{d\,t} = -\mathrm{A}\sqrt{\frac{g}{l}}\sin(t\sqrt{\frac{g}{l}} + \mathrm{C})$, A and C being constants depending upon the given conditions of the problem. Let, for instance, the length of the arc from the lowest point A to the point B, from which the heavy point begins to descend, $= s_1$ and let the time be reckoned from the moment when a descent commences; then, when $t = 0$, $s = s_1$, and $\frac{d\,s}{d\,t} = v = 0$; and, substituting these values in the above equations, it appears that $s = \mathrm{A}\cos\mathrm{C}$, and $0 = -\mathrm{A}\sqrt{\frac{g}{l}}\sin\mathrm{C}$; and hence $\mathrm{C} = 0$, and $\mathrm{A} = s_1$, and therefore



$$s = s_1 \cos t\sqrt{\frac{g}{l}}, \text{ and } v = -\frac{d\,s}{d\,t} = s_1\sqrt{\frac{g}{l}}\sin t\sqrt{\frac{g}{l}}.$$

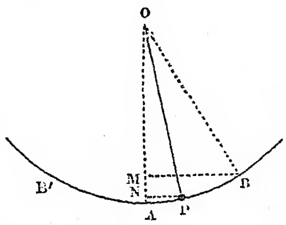
When the heavy point P arrives at A, $s = 0$, and therefore

$$\cos t\sqrt{\frac{g}{l}} = 0, \text{ and } t\sqrt{\frac{g}{l}} = \frac{\pi}{2}, \text{ or } \frac{3\,\pi}{2}, \text{ or } \frac{5\,\pi}{2}, \text{ or \&c.}$$

Hence the time of a semi-vibration, or time in which the heavy point first arrives at the lowest point A, is $\frac{\pi}{2}\sqrt{\frac{l}{g}}$, and the time of each complete vibration is $\pi\sqrt{\frac{l}{g}}$.

It appears, then,—1. That the time of vibration in a cycloidal arc is the same, whatever be the extent of the arc of vibration; 2. That the time of vibration is directly proportional to the square root of the length of the pendulum; and 3. That the time of vibration is inversely proportional to the square root of the force of gravity.

Properties of simple pendulums vibrating in circular arcs.



Let the heavy point P be suspended from an axis at O, and vibrate in the circular arc B A B′, of which O A, the length of the pendulum, is the radius; and let B be the point from which the descent commences, A the lowest point of the arc, and P the position of the heavy point at any time t. Through B and P draw the horizontal lines B M and P N to meet the vertical line O A in the points M and N; and let A M $= h$, A N $= x$, A P $= s$, and O A $= l$. Then v, the velocity at the point P, = the velocity acquired in falling through the height M N $= \sqrt{2g\,.\,\mathrm{MN}} = \sqrt{2g(h-x)}$; and, since s decreases as t increases, $v = -\frac{ds}{dt}$, and $\frac{dt}{ds} = -\frac{1}{\sqrt{2g(h-x)}}$; but

$$\frac{ds}{dx} = \frac{l}{\sqrt{2lx - x^2}}, \text{ and therefore } \frac{dt}{dx} = \frac{dt}{ds}.\frac{ds}{dx} = -\frac{1}{\sqrt{2g(h-x)(2lx-x^2)}}.$$

We are not able to integrate this expression in a finite form; but it can be expanded into a series of which the terms can be separately integrated, and in this manner the integral can be obtained to any required degree of approximation. Thus—

$$\frac{dt}{dx} = -\tfrac{1}{2}\sqrt{\frac{l}{g}}\frac{1}{\sqrt{hx-x^2}}\left(1-\frac{x}{2l}\right)^{-\frac{1}{2}} =$$

$$-\tfrac{1}{2}\sqrt{\frac{l}{g}}\frac{1}{\sqrt{hx-x^2}}\left\{1+\frac{1}{2}\frac{x}{2l}+\frac{1.3}{2.4}\left(\frac{x}{2l}\right)^2+\ldots+\frac{1.3\ldots(2n-1)}{2.4\ldots2n}\left(\frac{x}{2l}\right)^n+\ldots\right\}.$$

$$\text{Now} \int_h^0 \frac{x^n\,dx}{\sqrt{hx-x^2}} = \frac{2n-1}{2n}h\int_h^0\frac{x^{n-1}\,dx}{\sqrt{hx-x^2}}, \text{ and} \int_h^0\frac{dx}{\sqrt{hx-x^2}} = -\pi;$$

$$\text{therefore} \int_h^0\frac{x\,dx}{\sqrt{hx-x^2}} = -\frac{1}{2}\pi h, \int_h^0\frac{x^2\,dx}{\sqrt{hx-x^2}} = -\frac{1.3}{2.4}\pi h^2, \text{ and so on;}$$

but between the limits $x = h$ and $x = 0$, t is the time of a semi-vibration, and therefore the time of a semi-vibration is

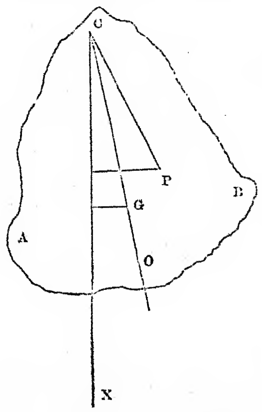
$$\frac{\pi}{2}\sqrt{\frac{l}{g}}\left\{1+\frac{1^2}{2^2}\frac{h}{2l}+\frac{1^2.3^2}{2^2.4^2}\left(\frac{h}{2l}\right)^2+\ldots+\frac{1^2.3^2\ldots(2n-1)^2}{2^2.4^2\ldots(2n)^2}\left(\frac{h}{2l}\right)^n+\ldots\right\}.$$

When the arc of vibration is very small, the second and all the succeeding terms of this series are so exceedingly small that they may ordinarily be neglected, and the time of a complete vibration represented by $\pi\sqrt{\frac{l}{g}}$, which coincides with that in a cycloid.

The second term of the series gives a correction to be added to the time of a vibration, $= \pi\sqrt{\frac{l}{g}}\frac{h}{8l}$, or $= \pi\sqrt{\frac{l}{g}} \times {\cdot}000019038\ d^2$, if d be the number of degrees in A B, half the arc of vibration.

If the time of vibration of a pendulum in a cycloidal, or infinitely small circular arc, be 1″, so that $\pi\sqrt{\frac{l}{g}} = 1$, the increment of the time for the circular arc $2\,d$ will be ${\cdot}000019038\,d^2$, and the time lost in a day will be $24 \times 60 \times 60 \times {\cdot}000019038\,d^2 = \frac{5}{3}d^2$, nearly. Thus if the arc of vibration be 4°, the time lost in a day will be $6''\frac{2}{3}$, nearly; if the arc be 2°, the time lost in a day will be $1''\frac{2}{3}$; if the arc be 1°, the time lost in a day will be $\frac{5}{12}''$; and if the arc be but $\frac{1}{2}°$, the time lost in a day will be but $\frac{5}{48}''$ only.

Connection between the simple pendulum and any body vibrating about a horizontal axis, and acted upon by gravity only.



Let A B C be a vertical section of the body made by the plane of the paper passing through the centre of gravity G, and cutting the axis of suspension perpendicularly in C; let P, P′, P″, &c., be the projections upon this plane of the particles m, m', m'', &c., and C x a vertical line through C; and let C $g = h$, the radius of gyration about an axis through the centre of gravity $= k$, C P $= r$, C P′ $= r'$, C P″ $= r''$, &c., G C $x = \theta$, and P C $x = \phi$, P′ C $x = \phi'$, P″ C $x = \phi''$, &c. The forces impressed on the particles m, m', m'', &c., are respectively $m g$, $m' g$, $m'' g$, &c., and the moments of these forces about the axis of suspension are $m g r \sin \phi$, $m' g r' \sin \phi'$, $m'' g r'' \sin \phi''$, &c. Therefore

$$\frac{d^2 \theta}{d t^2} = - \frac{\text{moment of impressed forces}}{\text{moment of inertia}}$$

$$= - \frac{g \left\{ m r \sin \phi + m' r' \sin \phi' + m'' r'' \sin \phi'' + \&c. \right\}}{m r^2 + m' r'^2 + m'' r''^2}$$

$$= - \frac{M g h \sin \theta}{M (h^2 + k^2)}$$

if M represent the sum $m + m' + m'' +$ &c., or the entire mass of the body. Hence

$$\frac{d^2 \theta}{d t^2} = - g \frac{h}{h^2 + k^2} \sin \theta.$$

In C G produced take C O $= \frac{h^2 + k^2}{h}$; then if the whole mass M were collected at O, and connected with the axis of suspension at C by a cord without weight, the moment of the impressed force would be M g . C O $\sin \theta$, while the moment of inertia would be M . C O^2, and therefore we should have

$$\frac{d^2 \theta}{d t_2} = - \frac{M g \, C O \sin \theta}{M . C O^2} = - \frac{g \sin \theta}{C O} = - g \frac{h}{h^2 + k^2} \sin \theta,$$

the same equation for determining the motion as before. Hence it appears that the time of vibration of the body A B C is the same as that of a simple pendulum whose length $l =$ C O $= \frac{h^2 + k^2}{h}$, and, in fact, that all the circumstances of the motion of the point O are the same as if it were the heavy point of such simple pendulum.

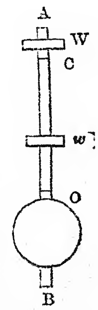
The point O is called the centre of oscillation; the point C, the centre of suspension; the vibrating body, a compound pendulum; and $l = \frac{h^2 + k^2}{h}$, the length of the corresponding simple pendulum.

Since $l = h + \frac{k^2}{h}$, and hence $l - h = \frac{k^2}{h}$, and $h = \frac{k^2}{l - h}$, if the body be suspended anew on an axis through O parallel to that through C, and l' represent in this case the length of the equivalent simple pendulum, then

$$l' = O G + \frac{k^2}{O G} = l - h + \frac{k^2}{l - h} = \frac{k^2}{h} + h = l;$$

so that C becomes now the centre of oscillation, or the centres of oscillation and suspension are reciprocal.

Kater's Pendulum.—This property was made use of by Captain Kater (Phil. Trans. for 1818) to determine the true length of the seconds pendulum in the following manner.



Let A B be the compound pendulum, C the point of suspension, W and w two weights which may be shifted from one position to another on the pendulum, and O the centre of oscillation of the pendulum, including W and w. The positions of C and O being first determined approximately by computation, knife edges are fixed at these points to form the parallel axes about which the pendulum is to be made to vibrate in the succeeding steps of the experiment. These knife edges are formed and fixed with great care, and being rested alternately upon horizontal agate planes, the weight W is shifted till the times of vibration about C and O are very nearly the same, and the adjustment is then perfected by moving the smaller weight w. The time of vibration is now carefully observed, and the distance C O accurately measured; and if l be this distance, and t the observed time of vibration, and L represent the length of the simple pendulum vibrating seconds, we have, since the lengths of simple pendulums are as the squares of their times of vibration,

$$t^2 : 1^2 :: l : L, \text{ and } \therefore L = \frac{l}{t^2}.$$

The corrections to be applied to the length of the simple pendulum for given errors in the construction of the compound pendulum are given in a Paper by Mr. Lubbock in the 'Philosophical Transactions' for 1830. The greatest error arises from a deviation for horizontality in the agate planes,—a deviation of 10′ increasing by about 6 the vibrations in 24 hours.

The construction of this pendulum has since been considerably simplified, consisting in its improved form of a plain straight bar, 2 inches wide, $\frac{1}{2}$ inch thick, and about $62\frac{1}{2}$ inches long. At the distance of 5 inches from one end of this bar is placed the vertex of one of the knife edges, and at the distance of 39 inches is placed the vertex of the other knife edge. The pendulum is made to vibrate nearly in the same time about both knife edges by filing away one of the ends of the pendulum, and the adjustment is perfected by means of two screws, which hold a small weight in a hole near one end of the bar.

The length L of the seconds pendulum having been determined, the accelerating force of gravity at the place of the experiment is immediately given by the equation $g = \pi^2$ L. Thus in the latitude of London the length of the seconds pendulum, L, is 39·1393 inches, and, consequently,

$$g = \pi^2 \times 39{\cdot}1393 = 386{\cdot}29 \text{ inches} = 32{\cdot}19 \text{ feet.}$$

The force of gravity varies in different latitudes, the increment above the force at the equator being nearly as the square of the sine of the latitude; and since the length of the seconds pendulum is directly proportional to the force of gravity, the increment in its length above the length at the equator varies also as the square of the sine of the latitude. Hence, if 39·1677 be the length of the seconds pendulum at the equator, and 0.20027 the increment in its length at the pole, the length l of the pendulum in any latitude λ, is given by the equation

$$l = 39{\cdot}01677 + 0{\cdot}20027 \sin^2 \lambda.$$

Since the force of gravity without the earth's surface varies in the same latitude inversely as the square of the distance from the earth's centre, and the number of vibrations made by a pendulum in a day varies inversely as the time of vibration,

and therefore directly as the square root of the force of gravity, it follows that the number of vibrations in a day varies inversely as the distance from the earth's centre. If, then, n represent the number of vibrations in a day at the earth's surface, and δn the number of vibrations lost, when the pendulum is carried to the height h above the surface,

$$\frac{n-\delta n}{n}=\frac{r}{r+h}=1-\frac{h}{r} \text{ nearly};$$

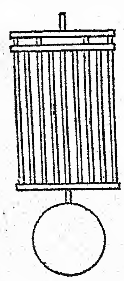
and the number of vibrations lost in a day is given approximately by the equation

$$\delta n=\frac{n h}{r}.$$

Compensation Pendulums.—Besides the variation in the time of vibration of a pendulum arising from the variation of gravity in different latitudes, and at different altitudes, there may be further a source of irregularity in the variation of the actual length of the pendulum, arising from the expansion or contraction of its material under different degrees of heat. To remove this defect, so important an object when the pendulum is employed as a constant time-keeper, various methods have been invented for constructing compensation pendulums, in which, notwithstanding the expansion of their several parts, the length of the equivalent simple pendulum, or distance between the centre of oscillation and the point of suspension, shall remain constantly the same. The first compensation pendulum appears to have been constructed by George Graham, who, after repeated trials, succeeded, in the year 1721, in forming a mercurial pendulum, in which the compensation was found to be so far effected, that its error in the extremes of temperature was reduced to $\frac{1}{8}$th the error in an ordinary pendulum.

The idea of arranging bars of different metals in such a manner as to form a compensation pendulum, having also been suggested by Graham, though he himself failed in accomplishing it, roused the ingenuity of other mechanics, and in 1726, Harrison, a carpenter, of Barton in Lancashire, succeeded in constructing the Gridiron Pendulum. Various modifications of compensation pendulums have since been made, but none have been found to excel the inventions of Graham and Harrison, which are still used in the construction of astronomical clocks.

Graham's Mercurial Pendulum consists of a rod of steel about 42 inches long, branched towards its lower end, so as to embrace a cylindrical glass vessel 7 or 8 inches deep, and having $6\frac{8}{10}$ inches of this depth filled with mercury; but the exact quantity of mercury, being dependent on the weight and expansibility of the other parts of the pendulum, must be determined by experiment. When the temperature increases, the steel rod is lengthened, while the mercury rises in the cylinder; but when the temperature decreases, the steel is shortened, and the mercury falls in the cylinder. By a proper adjustment, then, of the quantity of mercury, the effect of the lengthening or shortening of the rod is neutralised by the rising or falling of the mercury, and the centre of oscillation is kept at an invariable distance from the point of suspension.



Harrison's Gridiron Pendulum consists of five rods of steel and four of brass, placed in an alternate order, the middle rod, by which the bob or weight is suspended, being of steel. These rods are connected by cross pieces in such a manner, that while the expansion of the steel rods has a tendency to lower the bob, the expansion of the brass rods acts upwards, and tends to raise it; so that by duly proportioning the lengths of the two classes of rods, the centre of oscillation is kept at an invariable distance from the point of suspension, and the length of the equivalent simple pendulum remains constantly the same.

Amongst those who have succeeded in constructing compensation pendulums may be mentioned Regnault, Deparcieux, Julien le Roy, Ellicot, Hooke, F. Berthoud, Troughton, Dr. G. Fordyce, Ward, Adam Reid, Doughty, Ritchie, and Hardy.

Since the isochronism of the vibrations, independently of the length of the arc of vibration, is peculiar to pendulums vibrating in cycloidal arcs, it might be supposed that it would be advantageous to make the pendulum vibrate between cycloidal cheeks; and such a construction was in fact adopted for some time after its first invention by Huygens. Upon further consideration, however, it appears that in this case the centre of oscillation no longer occupies the same point of the pendulum in different parts of its path, from the circumstance of the virtual point of suspension, which is now the point of contact with the cycloidal cheek, continually varying. The vibrations of a compound pendulum, then, between cycloidal cheeks are not isochronous, nor has the theory of their motion been ever investigated, that we are aware of. Furthur objections to such pendulums also arise from the difficulty of giving to the cheeks the true cycloidal form, and the improbability of their long retaining it, supposing it once given.

The vibrations of actual pendulums are manifestly affected by the resistance of the air, the friction at the axis of suspension, and the maintaining power which is necessary to keep the pendulum vibrating for any length of time. Professor Airy, in the 'Cambridge Philosophical Transactions,' 1826, has determined, by the principle of the variation of parameters, general formulæ remarkable for their simplicity, for the alteration in the time and extent of the vibrations of a pendulum when acted upon by any small disturbing force whatever. By applying these formulæ to the disturbing forces above mentioned, it appears that, though the arc of vibration is diminished, the time of a vibration is not affected either by a constant friction at the axis of suspension, or by the resistance of the air; and further, that if an impulse be given to the pendulum at its lowest point only, the time of vibration remains unaltered. In the dead-beat escapement, the maintaining power acts on the pendulum for a small space near the middle of the vibration only, and Professor Airy, in the Paper above referred to, comes to the conclusion that this escapement is far superior to any other.

Ballistic Pendulum, *Cannon Pendulum*, and *Musket Pendulum*.*—The name *ballistic pendulum* was given by Robins to an apparatus invented by him for ascertaining the velocities of military projectiles, and thence comparing the effective powers of different specimens of gunpowder. This apparatus consisted of a large block of wood, suspended vertically by a strong horizontal axis, to which it was attached by a firm iron stem. Of late years, however, considerable improvements have been made by the Military Engineers of France in the details of the construction of ballistic pendulums, and the arms themselves from which the projectiles are fired have been suspended and adjusted, so as to form pendulums of equal value, and to measure by their arc of recoil the force of the explosion. To these suspended guns, as well as the suspended blocks which receive the shot, the French have extended the name ballistic pendulum, while they distinguish the one from the other by giving to the latter the name of the receiver pendulum, and to the former that of cannon pendulum, musket pendulum, &c., according to the nature of the arms suspended. English and American writers, however, still restrict the term ballistic pendulum to that which receives the shot.

The principal conditions to be fulfilled, as far as possible, by the construction of the pendulum, are—

* See also "Projectiles," p. 155.

1. That the pendulum should be capable of sustaining, without injury, the impact of balls of the largest calibre intended to be received by it, moving with the greatest velocity that can be given to them.

2. That the *core*, or part of the block which receives the impact of the ball, should be susceptible of being easily and quickly renewed after each fire.

3. That the frame of the cannon pendulum should be capable of receiving guns of various calibres.

4. That arrangements should be made in each pendulum for adjusting the height of its centre of oscillation, so as to make it coincide with that of the line of the fire, in order to prevent violent shocks on the axis of motion.

5. That the apparatus should not be liable to be affected by hygrometric changes in the atmosphere.

We proceed to describe briefly the contrivances by which, in the most improved forms of the pendulum, it has been sought to fulfil the above conditions.

The *pendulum block* is of cast iron, in the form of the hollow frustrum of a cone, with a hemispherical bottom; and, in order to give it the requisite strength, it is closely hooped with wrought iron over all the conical part, except in the places where it is embraced by the suspension straps. In the hollow of the pendulum block is placed the core, which is to receive the shot, and its axis should therefore coincide with the line of fire.

The opening in the face of the block is partially closed by an iron plate; and the point struck by the ball is marked by the hole made in a sheet of lead, which is placed over the opening in the plate, and retained by a washer, or smaller iron plate, bolted to the large one. Vertical and horizontal scales, drawn on the face of the small plate, serve, by means of an easy reference, to measure the position of the point struck by the centre of the ball.

Core of the pendulum block.—The hemispherical bottom of the core is formed of a block of lead, which serves to counterpoise the weight of the front part of the block, and thus facilitates the adjustment of the axis in a horizontal position.

The sand which receives the impact of the balls is contained in cases made of strong leather stretched over iron frames: the ends of these cases are closed with soft boards about ⅜ inch thick. In order to fill one of these cases or bags, it is placed on its small end, the boards forming the bottom are laid down on pins intended to support them, and if there be any openings through which the sand might escape, they are closed with shavings, &c.: the sand is then put in and settled with a small rammer. When nearly filled, the bag is placed on the platform of a balance, and its weight properly adjusted; after which the boards forming the head are fastened on by small nails driven into wooden plugs in holes on the inside of the hoop which forms the larger end of the frame.

Four of these bags form a set for filling the pendulum block; and an interval of about 3 inches is left at the mouth of the block to admit any compensating weights which may be required to make up the proper charge, and which are in the form of large rings, made of iron, of different sizes, according to the weight required. The vacant space in the mouth of the block is requisite for containing the sand displaced by the shot.

Suspending apparatus.—The block is attached by means of four straps of wrought iron to a horizontal shaft of the same material. The shaft terminates at each end in knife edges made of hardened steel welded to the iron; these knife edges are rounded on a radius of 0·06 inch, and rest in Vs, the bottom parts of which are rounded on a radius of 0·1 inch; while the inclination of the sides of the Vs is so arranged with reference to that of the planes of the knife edges as to allow the pendulum to

vibrate through an arc of 30°. The adjustment of the Vs is regulated by means of wedges.

The arc of vibration of the pendulum is measured on a brass limb; a slide, also of brass, moving on this limb, is pushed forward by an index attached to a bar, which is connected with the suspension straps at the proper distance from the axis.

In the *cannon pendulum*, the suspension frame, the supports, and the general arrangement, are similar to those of the ballistic pendulum as described above.

In the *musket pendulum*, and the ballistic pendulum for practice with the *musket*, the principles of construction are the same, the chief deviation being in the manner of forming the core: this core in the French pendulum consisted of a block of lead, which received the ball, and which was renewed at each shot; but Captain Mordecai, of the United States' Ordnance Department, in his experiments at Washington in the years 1843-44, substituted a core composed as follows:

1st. A block of hard wood, turned to fit the bottom part of the pendulum block.

2nd. A conical block of lead, faced with a plate of iron, occupying nearly the centre of the core.

3rd. A block of hard wood, turned and cut to such a length as just to fill the pendulum block, and to bear against the face-plate, which is formed of wood, and pressed against the front of the pendulum by an iron clamp. The point struck by the ball is marked by the perforation of the face-plate.

Adjustments of the pendulums.—The pendulums must always be adjusted for the positions of the centres of gravity and oscillation, for the horizontality of their shafts, and when the ballistic and cannon or musket pendulums are used together, the shafts of the two pendulums must be adjusted for parallelism.

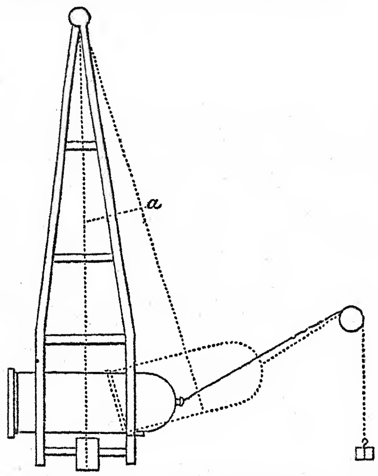
Adjustment of the shafts.—This adjustment is corrected, if necessary, by moving one or more of the seats in which the Vs are placed. It is verified for horizontality by a level; and for the parallelism of the two shafts as follows: Two plumb-lines are suspended to the ends of a needle attached to each shaft in a direction perpendicular to its axis; four other plumb-lines are suspended in the axis of the gun and block (on the front and rear of each), and, when the adjustment is perfect, these eight plumb-lines should hang in the same plane.

Adjustment of the centres of oscillation.—The centre of oscillation of each pendulum must coincide very nearly with the line of fire; and its position having been determined in the manner hereafter to be explained, it is to be raised or lowered, if necessary, by placing weights on the upper or lower of the large screw-bolts which connect the front and rear straps above and below the gun or the block.

Adjustment of the centre of gravity.—The centre of gravity must be situated in the intersection of the vertical plane containing the axis of the cannon or block and the plane perpendicular to this axis which passes through the axis of motion. Deviations from the proper position of the centre of gravity may be caused by variations in the charge of the gun or block. This adjustment is corrected by sliding backwards or forwards the weights which have been placed upon the large screw-bolts to adjust the centre of oscillation.

Moments of the pendulums.—By the moment of a pendulum we mean the product of its weight and the distance of the centre of gravity from its axis of motion, the weight being estimated in pounds, and the distance in feet. This moment ought to be determined with precision, since it enters into the formulæ for determining the velocity of the projectile. The weights of the several parts of the pendulums being accurately determined, and also the positions of their centres of gravity, by balancing them on the edge of a square steel bar, the places of the centres of gravity of the entire systems, or the moments of these systems, are easily calculated by the ordi-

nary formulæ; and by the same means the corrections for an alteration of the adjusting weights, or a change in the weight of the core of the block, or of the charge of the gun, are readily obtained. The results of these calculations may be verified at any time experimentally, without dismounting the pendulums, in the following manner: A cord being fixed at any convenient point of one of the pendulums, is passed over a fixed pulley, and by means of a known weight attached to its extremity, pulls the pendulum through an angle which is accurately measured. The pulley should be large, turning on a small and well-greased axis, so that the friction may be neglected without introducing any appreciable error. Now, having marked conspicuously the intersection with the surfaces of the block or gun of the plane passing through the axis of motion and the centre of gravity, which plane is vertical when the pendulum hangs freely, the inclination of this plane under the action of the weight, which is the angle through which the pendulum is pulled, is easily observed.



Let, then, p represent the weight of of the pendulum;

h, the unknown distance of its centre of gravity from the axis of motion;

a, the angle through which the pendulum is pulled;

d, the perpendicular let fall from the axis of motion on the direction of the cord;

t, the tension of the cord, or the weight suspended from its extremity; and we have the relation

$$td = ph \sin a;$$

and hence the required moment $p\,h$ is given by the expression

$$p\,h = \frac{t\,d}{\sin a.}$$

Position of the centre of oscillation.—The distance of the centre of oscillation from the axis of motion, or length of the equivalent simple pendulum, is obtained by setting the pendulum in motion and observing the time of a certain number of vibrations. Thus, if n be the number of vibrations in the time t, g the force of gravity at the place of observation, π the ratio of the circumference of a circle to its diameter, and l the distance of the centre of oscillation from the axis of rotation.

$$l = \frac{g\,t^2}{\pi^2\,n^2};$$

or if L be the length of a seconds pendulum at the place of observation,

$$l = \frac{\mathrm{L}\,t^2}{n^2}$$

When the distance l' of the centre of oscillation from the axis of rotation is ascertained from any given condition of the system, the adjusting weight w, requisite to bring that centre to any desired distance l, may be computed very nearly by the formula

$$w = \frac{p\,h\,(l - l')}{d\,(d - l)},$$

$p\,h$ being the moment of the pendulum, and d the distance of the adjusting weight from the axis of rotation.

Formulæ for computing the velocity of the ball.

1. *By the ballistic pendulum:*

Let p represent the weight of the pendulum.

h the distance of its centre of gravity from the axis of motion.

l ,, ,, oscillation ,, ,,

i ,, the point of impact ,, ,,

b the weight of the ball.

v the velocity with which the ball strikes the pendulum.

a the angle of the first semi-vibration of the pendulum.

The mass of the ball being $\frac{b}{g}$, its quantity of motion at the instant of impact is $\frac{b\,v}{g}$, and the moment of this quantity of motion about the axis of motion is $\frac{b\,v\,i}{g}$.

After the impact, all parts of the pendulnm, including the ball, move with the same angular velocity; and if ω represent this angular velocity, the quantity of motion communicated to an element $d\,m$ at a distance r from the axis of motion is $\omega\,r\,d\,m$, and the moment of this quantity of motion about the axis is $\omega\,r^2\,d\,m$. The sum of all such moments, or the moment of the quantity of motion of the whole pendulum, is $\omega \int r^2\,d\,m$, the integral being taken for every particle of the pendulum, including the ball. Now, by the previous adjustment of the pendulums, the point of impact cannot be far from the centre of oscillation, and the position of this centre may therefore be assumed to remain constant without introducing any sensible error. We have therefore

$$l = \frac{\text{moment of inertia}}{\text{moment of the mass}} \quad \frac{\int r^2\,d\,m}{\frac{p}{g}h + \frac{b}{g}i};$$

and hence

$$\omega \int r^2\,d\,m = \omega\,.\,\frac{(p\,h + b\,i)\,l}{g};$$

and, since this must be equal to the moment of the quantity of motion of the ball before impact,

$$\frac{b\,v\,i}{g} = \omega\,.\,\frac{(p\,h + b\,i)\,l}{g},$$

$$\text{and } v = \omega\,.\,\frac{(p\,h + b\,i)\,l}{b\,i}.$$

The velocity of the centre of oscillation is $l\,\omega$, and since this point moves as though it were isolated, its velocity at the lowest point of its course is also that due to an altitude equal to the versed sine of the angle of semi-vibration; so that

$$l\,\omega = \sqrt{2\,g\,l\,(1 - \cos a)} = \sqrt{2\,g\,l\,.\,2\sin^2\tfrac{1}{2}\,a} = 2\sin\tfrac{1}{2}\,a\,\sqrt{g\,l};$$

$$\text{and therefore } v = 2\sin\tfrac{1}{2}\,a\,\frac{(p\,h + b\,i)\sqrt{g\,l}}{b\,i}.$$

In a set of experiments with balls of the same kind and calibre, since $b\,i$ is small in comparison with $p\,h$, no sensible error will be introduced by assigning to $b\,i$, in the numerator of the above expression, a constant value equal to the mean weight of the balls, multiplied by the mean distances of the points struck from the axis of suspension. By this assumption the whole term $(p\,h + b\,i)\sqrt{g\,l}$, becomes constant for one

set of experiments; and the value of this term being found, the formula is extremely simple and adapted to logarithmic computation. Since $2 \sin \frac{1}{2} a =$ chord of a, the velocity is directly proportional to the chord of the arc of semi-vibration, and inversely proportional to the product $b\,i$.

2. *By the gun pendulum.*—The same notation being employed as for the ballistic pendulum, the moment of the quantity of motion of the pendulum is

$$\omega \frac{p\,h\,l}{g} = 2 \sin \tfrac{1}{2} a \frac{p\,h}{g} \sqrt{g\,l}.$$

As the ball and wad leave the muzzle of the gun together, their quantity of motion is $\frac{(b + w)\,v}{g}$, w being the weight of the wad. The expansive force of the gunpowder which produces this quantity of motion may be considered as acting on an area of a great circle of the ball; and as it acts with equal intensity on the annulus between the ball and the bore, driving out a portion of the elastic fluid past the ball, the quantity of motion will be increased by this circumstance in the proportion of the area of the cross section of the bore to that of a great circle of the ball, or in the proportion of the square of the diameter of the bore to the square of the diameter of the ball. The quantity of motion, therefore, of the ball and wad, and of the fluid which escapes past the ball, all taken together, is

$$\frac{(b + w)\,v}{g} \times \frac{D^2}{d^2},$$

and its moment about the axis of suspension is

$$\frac{(b + w)\,v\,i}{g} \cdot \frac{D^2}{d},$$

D and d being the diameters of the bore and ball respectively, and i being now the distance from the axis of suspension to the axis of the gun.

Again, if c' be the weight of the cartridge, including the bag, and the elastic fluid behind the ball be assumed to have a mean velocity equal to half that of the ball at the moment the ball leaves the gun,* the quantity of motion of the inflamed powder and of the cartridge-bag is represented approximately by $\frac{1}{2} \frac{c'\,v}{g}$, and its moment with respect to the axis of suspension by $\frac{1}{2} \frac{c'\,v\,i}{g}$.

After the ball has left the gun, the elastic fluid still continues to expand, and, in consequence of the resistance of the air, to re-act on the pendulum and increase its recoil. The quantity of motion due to this cause may be considered proportional to the quantity of powder in the charge, and may therefore be represented approximately by $\frac{c\,m}{g}$, c being the weight of the powder, and m a constant multiplier to be determined by experiment. The moment, then, of this quantity of motion about the axis of suspension is $\frac{c\,m\,i}{g}$.

The sum of the moments of all the quantities of motion of the ball and the charge is therefore

$$\frac{(b + w)\,v\,i}{g} \cdot \frac{D^2}{d} + \frac{1}{2} \frac{c'\,v\,i}{g} + \frac{c\,m\,i}{g},$$

and this must be equal to the moment of the quantity of motion of the pendulum;

* Hutton, 37th Tract. Prob. 19.

so that

$$\frac{(b + w)\, v\, i}{g} \cdot \frac{D^2}{d^2} + \tfrac{1}{2}\frac{c'\, v\, i}{g} + \frac{c\, m\, i}{g} \quad 2 \sin \tfrac{1}{2}\, a\, \frac{p\, h}{g} \sqrt{g\, l};$$

and hence

$$v = \frac{2 \sin \frac{1}{2}\, a\, \dfrac{p\, h \sqrt{g\, l}}{i} - c\, m}{(b + w) \cdot \dfrac{D^2}{d^2} + \dfrac{c'}{2}}.$$

To prevent the ballistic pendulum from being acted upon by the blast of the gun, the cannon pendulum should be placed at a distance from the ballistic pendulum of not less than 50 feet, and a screen should be placed at some little distance in front of the face of the pendulum block, with a hole in it of about 12 inches diameter, for the passage of the shot.

The musket pendulum may be set up at about 10 feet distance from its ballistic pendulum, and a screen, having in it a hole of about 2 inches diameter, should be placed in front of the face of the pendulum block, at some little distance, say 2 feet.

Captain Mordecai, from the results of his experiments at Washington, draws the conclusion, that the only reliable mode of proving the strength of gunpowder is to test it with Service charges, in the arms for which it is designed, for which purpose the pendulums are perfectly adapted.

For powder to be used in cannons, he advises the cannon pendulum alone to be made use of, as its indications correspond remarkably well with those given by the ballistic pendulum, and the use of the large ballistic pendulum is difficult, slow, and expensive. For the proof of powder for small arms, he recommends the small ballistic pendulum to be fired at from a barrel set in a permanent frame.

The same gentleman states that in a 24-pounder gun new cannon powder should give, with a charge of ¼th, an initial velocity of not less than 1600 feet, to a ball of medium weight and windage; and that the initial velocity of the musket-ball of 0·05 inch windage, with a charge of 120 grains, should be—

With new musket powder,	not	less than	1500	feet.
With new rifle powder,	,,	,,	1600	,,
With fine sporting powder,	,,	,,	1800	,,

He also comes to the conclusion, that the common éprouvettes are of no value as instruments for determining the relative force of different kinds of gunpowder.

PENETRATION OF PROJECTILES.*—The following Tables and Notes relate chiefly to the effects of artillery on fortifications and buildings connected therewith,—its powers in the field under various conditions and positions being foreign to the principal object.

The information whence these notices are derived has been taken from the 'Aide-Mémoires' in the French Service, 'Journal des Sciences Militaires,' &c.; Belidor, &c. Several notes have been forwarded to me by individuals, and are included; a few are my own. The French measures and weights have been frequently retained, having in some instances their equivalents given in English terms.

The following Table is the result of the experiments at Metz, and of calculations founded thereon, according to Hutton's Theory.

* By the late Colonel Emmett, R.E.

Penetration into Masonry, good Rubble, as that of the Revetments at Metz constructed by Vauban. (Aide-Mémoire à l'Usage des Officiers d'Artillerie.)

Boulets.	Charges.	Aux Distances de Mètres.									English Measures.	
		25	50	100	200	300	400	600	800	1000	Diam. of Shot.	Charge Avoirdup.
	k.	m.	m.	m.	m.	m.	m.	m.	m.	m.	inches.	lbs.
36	6·00	0·680	0·670	0·650	0·605	0·565	0·530	0·455	0·380	0·310	6·648	13·234
24	6·00	0·650	0·640	0·615	0·570	0·530	0·490	0 415	0·340	0 275	5·808	13·234
	4·00	0·615	0·605	0·580	0·535	0·495	0·460	0 385	0 310	0·250	...	8·823
	3·00	0·575	0·565	0·545	0·505	0·465	0·425	0 350	0 285	0·230	...	6·617
	2·00	0 510	0·500	0·480	0·440	0·400	0·365	0 300	0 245	0·200	...	4·411
	1·50	0·440	0·430	0·410	0·370	0·335	0·300	0·245	0·200	0 165	...	3·309
16	4·00	0·570	0·555	0·530	0·485	0·445	0·405	0·325	0·255	0·195	5·074	8·823
	2 67	0·535	0·525	0·500	0·455	0·415	0·375	0·300	0·235	0·185	...	5·888
	2·00	0·495	0·485	0·465	0·425	0·385	0·350	0·275	0·215	0·170	...	4·411
	1·33	0·435	0·425	0·410	0·370	0·330	0·295	0·230	0·185	0·150	...	2·94
	1·00	0·380	0·370	0·350	0·310	0·275	0·240	0·190	0·155	0·130	...	2·206
12	2·00	0·480	0·470	0·445	0·405	0·370	0·330	0·255	0·195	0·155	4·610	4·411
	1·50	0·450	0·440	0·420	0·380	0·340	0·300	0·225	0·175	0·140	...	3 309
	1·00	0·395	0·385	0·365	0·330	0·290	0·255	0·190	0·155	0·125	...	2·206
	0·75	0 350	0·340	0·320	0·280	0·245	0·210	0·165	0·135	0 110	...	1·654
8	1·25	0·405	0·395	0·375	0·335	0·295	0·260	0·190	0·140	0·105	4·027	2·757

NOTES ON THE TABLE.

The above penetrations multiplied by

1·25 will give the penetration into masonry of moderate quality.
1·75 ,, ,, brick.
0·46 ,, ,, oolitic calcareous rock.

1. Shot fired at short distances from the wall, perpendicular to it, formed an *entonnoir*, the exterior diameter of which equalled five times the diameter of the shot,—the internal opening being cylindrical,—scattering splinters to a distance of 40 or 50 metres, and forming a train of fragments in front of 6 metres.

The shock of the shot loosens the masonry to a distance one-half greater than the diameter of the exterior of the opening, being for the 24-pr. = 1·15 metre; for the 16-pr. =·90; for the 12-pr. = ·80.

2. Shot fired against masonry with a charge of one-quarter their weight, usually break on a meridional plane of which the pole is the striking point.*

3. The effect of shells on masonry is little; they break the moment of striking with an ordinary charge, and with low charges make but little impression.†

4. By the trials at Metz, it appears that a masonry scarp may be breached at the distance of 40 to 60 metres by oblique fire; with a charge of ½ the weight of the shot, at an angle of 25° to 30°; and with that of ⅓rd at an angle of 40° to 45°.

5. The effect of shot of different calibres in breaching is nearly proportional to their weight (charges, it is presumed, being proportionate).‡

* This remark applies to shells: whether hollow shot have been fired against masonry I am not aware. The 8-inch shell weighs from 42 to 44 lbs.; the 8-inch hollow shot about 56 lbs.

† In 1810, trials were made at Glatz with shells from a 24-pr. against a wall of cut stone and brick, well built, and of several years' standing: the wall was 16 ft long, 7 high, and 4½ thick. The charges varied from 1¾ lb to 5¼ lbs. In every instance the shell was completely splintered,—the penetration into the masonry being from 9 to 18 inches,—the diameter of the opening from 1 foot 6 inches to 2 feet 7 inches; but the wall was not in the least shaken by them: but a single 24-lbs. shot fired from a howitzer with a charge of 1¾ lb. sensibly shook the wall and cracked it. The fuzes of the shell would have fired the charges about half the number of rounds.

‡ On comparing the number of rounds and the time requisite for making breaches with the

6. The heat produced by the concussion is great, particularly when the shot break. In both cases the lime appears to be partially calcined.

Experiments at Fort Monro Arsenal (United States) in 1839.

Calibre.	Charge.	Elevation.	Distance.	Mean Penetration.		
				Dressed Granite.	Potomac Freestone.	Hard Brick.
	lbs.	° ′	yds.	in.	in.	in.
Shot. 32.-pr. gun	8	1 0	880	3·5	12·	15·25
Shell. 8-inch sea-coast howitzer	6	1 35	880	1·	4·5	8·5

The solid shot broke against the granite, but not against the freestone or brick.

The shells broke into small fragments against each of the three materials.

The circumstances attending the penetration of the shot and shells correspond with those above stated in the experiments at Metz. The walls used as targets were built of dressed stone, and of the best bricks, laid in hydraulic cement; but being isolated walls (10 feet square of each material, and 5 feet thick, with 3 counterforts), and being battered before the masonry was perfectly set, the effect of the projectiles in shattering the masonry around the point struck was greater than indicated by the experiments referred to at Metz.

VARIOUS NOTES.

1. Effects of a long 24-pr. on a scarp of columnar basalt of the Rhine, generally raised in blocks of 4 to 5 feet by 8 to 10 inches in diameter,—frequently used as headers,—distance 160 feet,—

   charge of 10 lbs.—penetration into the basalt 10 inches.
   ,, 4 lbs. ,, ,, 4 inches.

   Twenty rounds were fired, giving the same results.
2. Bermuda hard limestone walls of rubble masonry with ashlar facings of 2′ × 1′ × 1′ 6″, being an old lime-kiln. At 40 feet, three rounds of a 32-pr. of 9 feet 6 inches were fired: the first two penetrated 5 feet 6 inches each; the third, entering the first opening, passed through the wall, which was 8 feet 6 inches thick, and struck the opposite side.
3. A masonry embrasure was ruined at 175 yards by 15 rounds from a 24-pr., 10 lbs. charge,—and another in 20. (Neither place nor particulars have been given me.)
4. *Effects on concrete.*—A magazine built at Woolwich for the purpose of experiment: span of arch 18′—rise $\frac{1}{3}$ to $\frac{1}{4}$—thickness nearly 4 feet; abutments 4′ 6″ to springing of arch—thickness 7′ 6″—*dos d'âne* on the arch. Five shells were fired at 45° from two 13-inch mortars, distant 500 yards,—shells loaded with sand, weighing 200 lbs. All struck the building,—two only fairly upon the arch, which they penetrated to about $\frac{1}{3}$rd their own diameter, pulverizing the concrete 10 to 12 inches, forming craters 2 feet and 2 feet 6 inches diameter. The arch was cracked by each, vertically from the side of the crater—the cracks shewing themselves through on the soffit of the arch. The two struck on the same horizontal plane, distant 4 feet 6 inches, and a crack was made between the two craters.

Two shells were fired at 75° elevation; the effect of one on the rear of the building was similar to those at 45°; the other entered the crater of one of the first, enlarged it to 3 feet, and pulverized the concrete to 15 inches deep.

24-pr. and 16-pr. (Metz), their proportions appear to be in an inverse ratio to the weight, being nearly as 16 to 22. In both cases the consumption of powder and of shot was nearly equal.

Two shots fired at the abutments from a 24-pr., distant 250 yards, penetrated about 3 feet 10 inches, forming craters 3 feet diameter, and casting a few splinters to a distance of 40 to 50 yards. These likewise cracked the mass, and judging from the effects of two shots subsequently fired, it is probable the arch would soon have been brought down.

It is to be remarked that the abutments, built on soft ground, had settled considerably, and split the arch along its entire length, forming a crack $\frac{3}{10}$ inch open—this before trial—and that the concrete was not dry.

5. At the siege of Landau, on a magazine of Vauban's construction, upwards of 80 shells fell without doing it any damage; the same occurred at Ath and other places. At that of Tournay, upwards of 45,000 shells were thrown into the citadel, of which the greatest number fell on two similar magazines, semicircular arches, as at Landau, without doing them any damage; whilst two souterrains arched *entiers point*, and covered over for 40 years with 5 to 6 feet of earth, were *enfoncé*. All Vauban's have stood without failure.—(*Belidor.*)

6. At the siege of the Castle of Scylla in 1806, a battery of field-guns was placed in a position to bear into the embrasures of the casemates, out of view of the artillery of the castle. On the fall of the castle, the effects of the fire exhibited by the indentations of the walls, and other marks of destruction and slaughter, proved that, under the usual construction of the embrasure, casemates would be untenable, if exposed to direct fire.—(*Jones.*) (See article 'Breach,' vol. i.)

Penetrations in settled Ground, half Clay, half Sand.

Shot.	Charge.	Distances in Metres.									English Measures.	
		25	50	100	200	300	400	600	800	1000	Diam. of Shot.	Charge Avoirdupois.
	k.	m.	m.	m.	m.	m.	m.	m.	m.	m.	inches.	lbs.
36	6·00	2·77	2·70	2·60	2·47	2·37	2·27	2·09	1·92	1·77	...	13·234
24	6·00	2·75	2·67	2·52	2·31	2·14	2·02	1·84	1 68	1·54	...	13·234
	4·00	2·55	2·48	2·35	2·18	2·06	1·96	1·78	1·62	1 48	...	8 823
	3·00	2·35	2·29	2·20	2·07	1·97	1·88	1·71	1 57	1·45	...	6 617
	2·00	2·12	2·09	2·03	1·92	1·83	1·75	1·59	1·45	1·33	...	4 411
	1·50	1·94	1·90	1·84	1·75	1·67	1·60	1·46	1·32	1·20	...	3·309
16	4·00	2·40	2·31	2·18	1·97	1·83	1·72	1·56	1·42	1·28	...	8 823
	2·67	2·20	2·12	2·02	1·87	1·76	1·67	1·52	1·38	1·25	...	5·888
	2·00	2·05	1·99	1·91	1·77	1·69	1·61	1·47	1·33	1·20	...	4·411
	1·33	1·85	1·80	1·73	1·65	1·57	1·50	1·36	1·24	1 13	...	2·94
	1·00	1·69	1·66	1·62	1·54	1·47	1·40	1·28	1·16	1 05	...	2·206
12	2·00	1·65	1·61	1·52	1·39	1·29	1·22	1·09	0·98	0·89	...	4·411
	1·50	1·54	1·50	1·42	1·32	1·24	1·17	1·05	0 95	0·86	...	3·309
	1·00	1·39	1·36	1·29	1·22	1·15	1·09	0·98	0·89	0 82	...	2·206
	0·75	1·27	1·24	1·20	1·13	1·06	1·01	0·92	0·84	0 78	...	1·654
8	1·25	1·43	1·39	1·32	1·19	1·10	1·02	0·90	0·81	0 73	...	2·757
Howitzers.												
22c.	2·00	1·23*	1·20*	1·15*	1·06	0·98	0·90	0·77	0·66	0 59	8·661	4·411
	1·50	1·09*	1·06	1·02	0·94	0·86	0·79	0·69	0·61	0·55	...	3·309
	1·00	0·88	0·86	0·82	0·75	0·70	0·65	0·58	0·53	0·49	...	2·206
	0·50	0·58	0·57	0·55	0·53	0·51	0·49	0·45	0 42	0 40	...	1·103
16c.	1·50	1·34*	1·30*	1·24	1·14	1·04	0·95	0·78	0·64	0 56	6·299	3·309
	1·00	1·15	1·12	1·08	0·98	0·89	0·81	0·67	0·57	0·50	...	2·206
	0·75	1·01	0·98	0·94	0·85	0·78	0·71	0·60	0·52	0 46	...	1·654
25c.	1·00	1·13*	1·09*	1·04*	0·93	0·83	0·74	0·59	0·48	0·41	5·906	2·206
	0·50	0·85	0·82	0·78	0·70	0·63	0·57	0·46	0·39	0·34	5·906	1·103
12c.	0·27	0·69	0·67	0·63	0·55	0·49	0·44	0·37	0·31	0·26	4·724	·595
Wall-pieces.	0·010	0·25	0·27	0·22	0·15	0·11	0·08	0·04				
	0·008	0·30	0·28	0·24	0·19	0·15	0·12	0·08				

Note.—At the experiments at Metz, after breaching the masonry with 24-prs. at a distance of 31·9 metres, shells were fired from the 24-prs. and from 8-inch howitzers, to raze the parapet. The effect of the former was very inferior to that of the latter. Of the 8-inch shells, eighteen were fired loaded with 4·4 lbs., 2·2 lbs., and 3·3 s.lb charges (English). Of these, sixteen burst in the parapet with great effect. Previous trials had shewn that with a higher charge the shells split in striking sand. The parapet was reduced to 2 feet in thickness, and the firing discontinued.

With high charges, and at short distances, shells often split,—marked thus (*) in the preceding Table.

Penetrations in other Earths, obtained by multiplying the above numbers by the following factors:

Sand mixed with gravel	0·63
Earth mixed with sand and gravel, weighing above twice that of water	0·87
Settled vegetable soil, a made ground, sand and clay .	1·09
Humid stiff clay	1·44
Earth lightly settled	1·50
Earth recently removed	1·90

Sand, a sandy ground mixed with gravel, small stone, and chalk, resist shot better than strong clayey ground, or that which imbibes and retains water.

When earth is softened by long rains, or the melting of snow, shells penetrate nearly double the distance; the fuzes, if not driven home, are generally broken, and at times the shell is broken at the fuze-hole.

Penetrations of Shells in Earth, Wood, and Masonry.

Degrees.	Distances.	Settled Earth. 22c.	27c.	32c.	Oak Wood. 22c.	27c.	32.	Rubble Masonry of good quality. 22c.	27c.	32c.
	m.	m.	m.	m.	m.	m.	m.	m.	m.	m.
30	600	0·20	0·45	0·50	0·10	0·20	0·22	0·05	0·09	0·10
	1200	0·25	0·65	0·70	0·12	0·30	0·35	0·06	0·12	0·13
45	600	0·30	0·50	0·55	0·15	0·25	0·27	0·08	0·10	0·11
	1200	0·40	0·70	0·75	0·20	0·35	0·40	0·10	0·14	0·15
60	600	0·50	0·75	0·80	0·22	0·33	0·37	0·11	0·15	0·16
	1200	0·55	0·80	0·85	0·25	0·35	0·40	0·12	0·16	0·17
Under the greatest force of descent		0·60	0·85	0·90	0·25	0·35	0·40	0·12	0·17	0·18

22 centimetres = 8·661 inches English; 27 = 10·630; 32 = 12·599.

NOTES.

1. A battery of 24-prs. in breaching earthwork at 600 metres will consume from three to four times the ammunition required at 40 metres.
2. By experiment in Silesia, four shells of 6 po. 1 lig., and twenty-two of 24 lbs., fired with full charge, formed a breach in an earthen rampart, having a slope of 15° from the vertical, at a distance of 125 metres, of 8 feet wide at the summit, and 24 feet at the base.
3. Penetration of shells fired at 45° elevation into a firm earthen parapet:

$5\frac{2}{3}$ inches at	600 paces	. . .	6 inches.
$6\frac{1}{2}$,,	800 ,,	. . . .	1 foot.
9 ,,	2500 ,,	. . .	$2\frac{1}{3}$ feet.
11 ,,	900 ,,	. . . .	2 feet.
11 ,,	2800 ,,	. . .	3 feet.

4. At Strasburgh, three 12-inch shells, loaded with 13 lbs., were buried in strong earth at the following depths :

4 feet deep—the diameter of the entonnoir was 8 feet.
6 ,, ,, ,, 12 feet.
7 ,, ,, ,, 15 feet.

5. At Glatz, a very firm earthwork, 18 feet thick and 15½ high in front, was subjected to the fire of 5⅝-inch shells from 24-prs. at the distance of 500 paces ; charge, 5 lbs, ; bursting charge, 13 oz. After 100 rounds, of which 33 burst in the parapet, an accessible breach was made ; and after 220 more rounds, of which 93 burst in the parapet, all cover was destroyed. It was thence concluded that 200 rounds of 5⅝-inch shells would, under similar circumstances, form a breach 18 fathoms long.

6. A field-battery, 12 feet thick, having three embrasures and ditch in front, was rendered untenable by 100 rounds from a 12-pr. howitzer at 500 paces ; 39 shells burst in the parapet.

7. At Berlin, in 1802, howitzers of 10 lbs. and 7 lbs. were placed on a glacis before the face of a bastion of mixed earth which had been constructed twenty years, o ascertain penetration, and whether the fuzes would ignite the charge of the shells. The penetration varied from 2 to 3¾ feet with a charge of 2½ for the 10 lbs., and from 1 foot to 2⅓ for the 7 livres with 1½ lb. charges. In each case the fuzes would have fired the powder half the number of rounds.

Results of Experiments at St. Omer in 1799, and at La Fere in 1817.

With the ordinary charge.	In an old parapet at 117 metres.		Parapet of recent construction 105 metres.	
	Mean.	Extreme.	Mean.	Extreme.
Field Guns.				
4-pr. . .	17 9	195c.	222c.	245c.
6 ,, . . .	211	219	271	281
8 ,, . .	244	276	321	325
16 ,, . . .	322	325	383	470
Siege Guns.				
16-pr. . .	352	395	383	410
24 ,, . . .	414	436	526	550
Gribeauval's Howitzer, chamber full . .	70	73	88	92
At 80 metres . . .	104	111	130	138
With the charge equal to ⅔ weight of shot at 40 metres :				
16-pr. . .		490		519
24 ,, . . .		530		659

Effects of Shells loaded with Service Charge.

	Howitzers of				Mortars of		
	12c.	15c.	16c.	22c.	22c.	27c.	32c.
Number of splinters (average)	17	22	21	33	33	18	22
Number of splinters weighing more than 0·1 kil. .	14	19	17	28	28	18	22

Cen.		E. ins.*
12	=	4·724
15	=	5·906
16	=	6·299
22	=	8·661
27	=	10·630
32	=	12·599

1. "On sinking into the ground and bursting, the entonnoirs are generally from two to three times the depth in diameter. With small charges no entonnoir is formed.

* The centimetre is 0·394 of an inch.

2. Splinters are often thrown to a distance of 600 to 800 metres.
3. The effects of very large shells are less in proportion than their weight.

Penetrations into Oak.

Shot.	Charge.	Distances in Metres.								
		25	50	100	200	300	400	600	800	1000
	k.	m.	m.	m.	m.	m.	m.	m.	m.	m.
36	6·00	1·66	1·63	1·58	1·48	1·38	1·29	1·12	0·95	0·80
24	6·00	1·60	1·56	1·50	1·39	1·29	1·20	1·02	0·85	0·70
	4·00	1·50	1·47	1·42	1·31	1·21	1·12	0·95	0·78	0·63
	3·00	1·41	1·38	1·33	1·23	1·14	1·05	0·88	0·72	0·58
	2·00	1·25	1·23	1·18	1·09	1·00	0·92	0·75	0·61	0·49
	1·50	1·08	1·06	1·02	0·93	0·85	0·77	0·62	0·50	0·40
16	4·00	1·39	1·35	1·29	1·18	1·08	0·99	0·81	0 65	0·50
	2·67	1·30	1·27	1·22	1·11	1·02	0·93	0·76	0·60	0·47
	2·00	1·21	1·18	1·13	1·04	0·95	0·86	0·70	0·55	0·43
	1·33	1·07	1·05	1·01	0·92	0·83	0·75	0·59	0·45	0·36
	1·00	0·94	0·92	0·87	0·78	0·70	0·62	0·49	0·38	0·30
12	2·00	1·17	1·14	1·09	0·98	0·89	0·81	0·65	0·50	0·37
	1·50	1·10	1·07	1·02	0·93	0·84	0·76	0·60	0·46	0·34
	1·00	0·96	0·94	0·90	0·81	0·72	0·64	0·49	0·38	0·29
	0·75	0·86	0·84	0·79	0·70	0·62	0·55	0·42	0·33	0·25
8	1·25	1·00	0·97	0·92	0·82	0·73	0·65	0·49	0·35	0·27
Howitzers.										
22c.	2·00	0·72	0·70	0·66	0·57	0·49	0·42	0·33	0·27	0·23
	1·50	0·59	0·57	0·53	0·46	0·40	0·35	0·28	0·24	0·21
	1·00	0·41	0·39	0·36	0·32	0·29	0·26	0·22	0·20	0·19
	0·50	0·23	0·22	0·21	0 21	0·19	0·18	0·17	0·16	0·15
16c.	1·50	0·84	0·81	0·77	0·68	0·60	0·52	0·38	0·30	0·25
	1·00	0·70	0·68	0·64	0·55	0·47	0·40	0·29	0·23	0·20
	0·75	0·58	0·56	0·52	0·44	0·37	0·32	0·25	0·21	0·18
15c.	1·00	0·70	0·68	0·64	0·55	0·46	0·38	0·26	0·20	0·16
	0·50	0·48	0·46	0·42	0·34	0·28	0·24	0·19	0·16	0·13
12c.	0·27	0·38	0·36	0·32	0·26	0·21	0·18	0·15	0·12	0·10
Balls.										
Wall-pieces.	0·010	0·085	0·080	0·065	0·045	0·027	0·018	0·008		
	0·008	0·090	0 085	0·075	0·057	0·045	0·035	0·025		

For diameter of shot and charges, in English, see former Tables.

Multipliers for the following Woods.

Beech, ash	1·0
Elm	1·3
Fir	1·8
Poplar	2·0

In oak, the fibres laterally separated by shot immediately close, leaving scarcely an opening; but the rent is often 2 yards long, and the splinters are thrown to the distance of from 12 to 15 metres.

In fir, all the fibres are completely broken, but the only effect produced is the void.

VARIOUS NOTES.

1. A 24-pr. shot at 175 paces, 10 lbs. charge, went through two rows of baulks with 2 feet 9 inches of rammed earth between them, and penetrated 6 to 12 inches into a wall behind.
2. An Austrian 24-pr. shot, with the ordinary charge, passed through a soft wood wall, cramped with iron, 9 feet thick. In a mass of $12\frac{1}{2}$ feet thick, the pene-

tration was from $9\frac{1}{2}$ to 10 feet; and with a charge of $9\frac{3}{4}$ lbs., $10\frac{1}{3}$ feet deep. A $5\frac{2}{3}''$ shell from a 24-pr. gun, with a charge of $4\frac{1}{2}$ lbs., entered $2\frac{1}{2}$ feet.

3. Experiment in New York Harbour, in 1814:

Penetration in a Target of White Oak Timber 5 feet thick.

Gun.	Charge.	Distance.	Penetration.	Remarks.
	lbs.	yards.	inches.	
32-pr.	11	100	60	shot wrapped with leather
Do.	11	150	54	to destroy windage.

4. Two oak walls, 13 feet high, 27 inches thick, and 50 feet apart, were battered at 800 paces with 9-inch shells. All passed through the first, and some reached the heart of the second wall, and bursting, ripped off the lining of the neighbouring portions, making rents of 4 to 5 feet long on both sides of the wall.

5. Effect on covered Batteries (Dublin Note).

   a. Battery 16′ × 10′ in the clear—joists 4 feet from centre to centre—bearing between sills 10 feet—plank 12″ × 6″, laid flat, covered with clay, a layer of fascines, and 3 feet of earth,—received at 600 paces—

   One 11-inch shell and 2 of $6\frac{1}{2}''$ at 60° elevation } without serious injury.
   One 11-inch „ and 2 of „ at 45° „ }

   b. Covered Mortar Battery in 1822.—Sills, joists, and covering baulks, 12′ × 12′—stanchions 4′ 8″ apart—joists same distance—9 feet wide in clear, having an earth covering of 5 feet.

   Three 11-inch shells, with 54 lbs. bursting charge, were buried 3 feet; nearly all the joists were broken, but the covering baulks were not injured.

   An 11-inch shell (5 lbs. charge), laid on the earth covering, shattered a covering baulk, and made a crater of 9 inches diameter, but did not damage the joist. Shells with 3 or 4 lbs. did not damage the baulk.

   The stanchions were lined with 3-inch plank, and when three 11-inch shells, with 5 lbs. charge, were burst within the battery, the supports were so crippled as to be unequal to bear the weight above. With 3 or 4 lbs. the damage was very great.

   c. At Antwerp, in 1832, a covered mortar battery stood proof that was struck with several shells—length 18 feet, breadth 12 feet; having five stanchions in the length of 16″ × 8″—with 8-inch framing—covering beams, spars of 6″ × 7″; then three layers of fascines, and 3 to 4 feet of earth.

6. In Silesia, in 1810, a shell of 6 p. 1 lig. 6 ps., fired from a howitzer at 330 metres, with a charge of $2\frac{1}{4}$ lbs., against a blockhouse $33\frac{1}{2}$ feet long, $19\frac{3}{4}$ feet wide, and $6\frac{3}{4}$ ft. high, penetrated the wall, and filled the interior with smoke, insupportable for six minutes, though the door and loopholes were open: shell loaded with 23 oz.

7. In 1778, a blockhouse at Schweidelsdorf was twice attacked without success: 2 guns and 1 howitzer were brought against it,—the first had little effect, but the howitzer set it on fire.

8. Blindages at Ciudad Rodrigo, when occupied by the French, placed against the interior wall of ramparts, or other substantial walls; formed of oak, 18 feet long, 8 inches square, 20 to 22 inches from centre to centre, placed on a sill 6 feet from the wall, their heads let into the wall; covered with 3-inch elm plank: a few of the blindages were injured, but none burst into by shells.

9. At the attack of Dresden, in 1813, by the Allies, two redoubts on the left bank of the Elbe, in advance of the stockade covering that part of the city, were

carried; but the stockade (apparently constructed of unsquared wood, trunks of trees), though partially injured, was nowhere breached by their artillery. (Rogniat.)

Effects of Shot and Shells against Shipping.

1st. Results of practice at the 'Prince George,' to try and compare the penetration of single shot from H.M.S. 'Excellent,' in October, 1838.—Portsmouth Harbour. Distance 1200 yards.

18-pr.	6 lbs. charge;	penetration	= $25\frac{1}{2}$ inches average.	
24-pr. of 9 feet 6 inches, .	8 lbs. ,,	,,	= 30	,,
32-pr. of 7 feet 6 inches, .	6 lbs. ,,	,,	= 30	,,
32-pr. of 9 feet, ...	6 lbs. ,,	,,	= 30	,,
32-pr. of 9 feet 6 inches, .	10 lbs. 11 oz.	,,	= 34	,,
68-pr. of 9 feet, or 8-inch gun,	12 lbs. ,,	,,	= 35	,,
,, ...	10 lbs. ,,	,,	= 35	,,
68-pr. carronade of 5 ft. 4 inches, ...	$5\frac{1}{2}$ lbs. ,,	,,	= 30	,,

Mem.—It is impossible to trace *with accuracy* the penetration of shot in the sides of a vessel, but it appears to increase with the weight of the shot. The destructive effects of the larger calibres, the 8-inch, must exceed those of less size.

2nd. Results of practice with live shells against the 'Prince George,' from H.M.S. 'Excellent,' moored at 1200 yards, in November, 1838:

Calibre.	Weight.	Length	Charge.	Elevation.	Penetration.
68-pr.	65 cwt.	9 feet	8 lbs.	$3\frac{1}{8}°$	= 35 mean.
,,	,,	,,	10 lbs.	$2\frac{7}{8}$	= 31 nearly.
,,	,,	,,	12 lbs.	$2\frac{3}{4}$	= 28 one round only.
32-pr.	40 cwt.	7′ 6″	6 lbs.	$2\frac{7}{8}$	= $21\frac{1}{2}$ mean.
,,	41 ,,	8 feet	6 lbs.	$2\frac{3}{4}$	= 28

Of 16 rounds from the 68-pr., 9 exploded in the vessel.
Of 14 ,, ,, 32-pr., 5 ,, ,,
Cases selected. 68-pr., or 8-inch gun.

Round 2 penetrated 18 inches in good wood through the ship's side, close to the after part; exploded instantly: the pieces of the shell tore down the cabin bulkheads, which made an immense number of splinters; a piece of the shell cut in two an iron saddle 3 inches in diameter.

Round 4 penetrated through the ship's side at the orlop deck, in good wood, 28 inches; cut off the foot of a strong rider 24 inches in thickness, completely shattering the remaining part of the rider, and drew out three large copper bolts from the ship's side; exploded and cut through a plank in the deck, made several large splinters, thrown to a distance of 20 to 30 feet, and pieces of the shell were found in several parts of the orlop.

Round 7 tore out the whole of the lower port-sill from aft, 24 inches thick, and all sound wood; crossed the deck and struck off the lower part of a solid oak knee, 16 inches thick, and shattered the remaining part of the knee 7 feet in length, rebounded from thence on the deck, tore up two planks, exploded and tore up all the cabin bulk-heads left standing after round 2.

Round 9 penetrated through the ship's side into the orlop deck, in fair wood, 28 inches; exploded, cut a strong oak knee, 15 inches thick, into two parts, struck and shattered a strong knee adjoining, sending seven large splinters, torn off the knees, on the opposite side of the deck. Fuze and pieces of shell scattered in various directions in the orlop.

Round 12.—32-pr. of 6′ 6″, 32 cwt. 5 lbs. charge, penetrated the ship's side below the water 13 inches, in good wood, and lodged behind a rider: the shell did not explode, but made an opening in the side, into which the water rushed with force, and in such a position that the carpenters present said it would have been impossible to have plugged or stopped the leak.

Round 13.—32-pr. of 7′ 6″, 40 cwt., 6 lbs. charge, penetrated at a port timber, in good wood, 2 feet thick; exploded instantly, blew out a large piece of the port timber, making several splinters: the aperture made with this shell was very great.

Previous to the practice from H.M.S. 'Excellent,' in 1824, experiments were made at Brest with Paixhan's guns against an 80-gun ship, the 'Pacificateur:' the results in both cases were similar; and the Committee of French Officers gave their opinion, officially, that no vessel whatever could hold out against a battery so armed at a distance of 300 to 500 toises. They also remarked that the risk of fire in a ship equipped for service would be very great, owing to the large quantity of cordage, &c., and the removals of ammunition in action.

In 1845 a series of experiments was made at Portsmouth from H.M.S. 'Excellent,' against the 'Swiftsure,' at the distance of 1443 yards, with results favourable to their application. In several instances the shells exploded on striking the side of the vessel, making breaches which, on or below the water-line, could not have been securely stopped at sea. Of those shells two struck within a few feet of each other, making a breach of upwards of 11 feet in length, and varying in breadth from $2\frac{1}{2}$ to 4, independently of greatly damaging and splintering the timbers.

The extreme range of shot fired *en ricochet*, full charge, with $1\frac{1}{2}°$ to $2°$ elevation on smooth water, is nearly equal to that obtained from the same gun fired at $5°$ elevation.

Effects of Red-hot Shot.

The use of shells will supersede in a great measure that of red-hot shot,—still the latter may be occasionally of great service. The fuze for the shell is sufficient for a range of 2400 yards, but the red-hot shot will have effect at the extreme length of its range. After striking water several times, the shot would still set the wood on fire. A temperature of 800° (barely dull-red heat) will suffice to inflame wood.

On the expedition against New Orleans, 1814-15, an American schooner was set on fire by a battery of field-guns (6-prs. or 9-prs.) after a few rounds, and blew up.

The actual effect of red-hot shot on the floating batteries at the siege of Gibraltar is not sufficiently satisfactory; and it is alleged that their danger would not have been great, had D'Arçon been allowed time to complete them according to his original plan.*

It is stated in documents procured at Madrid by the present Earl of Cathcart, during the Peninsular War, that the floating batteries were set on fire by the Spaniards themselves, to prevent their falling into our hands; and that but one instance occurred in which the red-hot shot had taken full effect.†

Effects of Shot on Cast Iron.

This material cannot be used when exposed to shot or shells without great danger to the defender, and from its own qualities is but ill adapted to works of defence.

1st. Shot, fired with a velocity of 140 metres per second, split into many pieces, and scatter splinters with some force.

2nd. A mass of cast iron, 1 metre square and ·30 metres thick, was split by shot fired with small velocity.

3rd. A platform (châssis d'affût de côte), of greater dimensions and weight than usual,

* See D'Arçon's explanation of the cause of the failure.

† The new liquid-fire shells are far more effective than hot shot.—*Ed.*

was broken in several places by a single shot of 8 lbs. with a velocity of 150 metres per second.

Effects of Shot on Lead.

In penetrating a mass of lead with a velocity of 225 metres, shot break, but make no external splinters. The opening made is sufficiently large to allow an easy withdrawal of the shot.

Penetration in a snow parapet 20 *feet thick, slightly rammed, and with some fragments of ice, on the St. Lawrence, opposite Montreal, in February,* 1840.

Service Charges.

Nature of Shot.	Range.	Greatest penetration.	Remarks.
	yards.	ft. in.	
9-pr.	600	8 0	A 9-pr. shot striking against a fragment of ice was broken into four pieces.
6-pr.	600	4 6	
Musket-ball	50	3 0	
,,	75	2 7	
,,	100	2 4	

Effects of Musketry.

1. The French musket-ball, from a distance of 22 metres, penetrates a gabion filled with sap fascines ·50 metre, and that of the *fusil de rempart*, ·60. A rolling gabion filled with fascines is proof against the *fusil de rempart* at 15 metres.

2. The penetration of musket-balls into woolsacks is double that into settled ground.

3. Musket-proof shutters,—

Of deal, 3 inches thick, covered on one side with rolled iron $\frac{1}{8}$ inch, are proof against a cavalry carbine at 10 to 14 yards; but with double cartridge the ball passed through.

With iron of $\frac{1}{8}$ inch on both sides, the shutter was proof against a double charge.

In trials with the ordinary firelock, rifle, and carbine, the latter, with double charge, gave the greatest penetration.

4. In battle, it has been calculated that five rounds per 1000 take effect; and of artillery, 10 in 100 rounds.

Penetration of Leaden Balls—Experiments made at West Point (United States) in 1837.

Penetration in seasoned White Oak.

Arm.	Charge.	Distances in Yards.							Remarks.
		3½	9	50	100	150	200	300	
	grains.	in.	in.	in.	in.	in.	in.	in.	
Musket	134	2·00	1·60	1·43	1·	0·66	0·55	0*	* 1 ball in 10 imbedded.
Musket	125	1·60	...	...	...	...	...	...	
Musket	90	1·60	...	...	...	...	...	...	
Common rifle	92	2·10	1·80	1·43	0·94	0·65	0·29	0†	† Indentation 0·2 inch.
Hall's rifle	70	1·12	1·70	0·63	0·53	0·40	0·0‡	...	‡ 2 balls in 10 imbedded

The musket, fired at 9 yards' distance, with a charge of 134 grains, 1 ball, and 3 buck-shot, gave for the ball a penetration of 1·15; buck-shot, 0·41 inch.

ADDITIONAL REMARKS.§

Breaching. Under the article 'Breach,' the Metz experiments have been already referred to; but as they are the most complete experiments directed to that object

§ By Major-General Portlock, R.E., F.R.S.

on record, it seems desirable that the result should be stated in such detail as will permit of their application as a datum of comparison for the operation of breaching generally.

The mode of breaching which the Metz Committee deduce from the experiments ought to be known and considered in a comparison with any other results.

In practice before an Enemy, the difficulties of following out closely definite principles may be great; but the object ought at least to be to approximate to them.

1. The breadth of the ditch and covert-way, the height of the counterscarp and crest of the covert-way, the height of the scarp, and thickness of the parapet, should be carefully ascertained.

From these data, reduced to a profile, it will be easy to determine the height of the horizontal section of the intended breach, in such a manner that the débris of the scarp wall may be sufficient to form a ramp of 1 to 2 slope. The height ought not to be less than a third of the scarp, that the débris may not be in the way, and at least equal to the thickness of the revetment at the line of section.

2. The elevation or depression of the gun, and the directions of each at the first series of discharges, should be so marked as to insure the shot striking the same points at each corresponding series. Beginning from the left and proceeding to the right, or *vice versâ*, each successive shot should strike the wall with 16-prs. at 1 metre, and with 24-prs. at $1^{m}\cdot25$ or $1^{m}\cdot50$ from the preceding one, through the whole line of section; and on the return from the right to the left, the shots should bisect the intervals between those of the preceding series.

It is essential that the section should progress equally throughout its whole length, and be continued only until the appearance of earth indicates that the revetment has been cut through, as the running out of much earth would cause the falling masonry to encumber the surface.

3. The vertical sections should be in number one for each gun, the distance between them never exceeding 10 metres, and, if possible, being less, so that the masonry may not be supported by more than one, or, at the most, two counterforts. The vertical section should begin by shots at short distances of $0^{m}\cdot3$, until the wall is well cut through at the base, and then the distances should be 1^{m}, proceeding first from the base upwards. Great care is necessary to keep the progressive advance of all the sections equal, as the oblique fall of part of the masonry from an inequality of support would seriously encumber the breach.

4. The wall having fallen, and the visible portions of the counterscarp having been destroyed, it is desirable to change two of the guns for 8-inch howitzers, to complete the destruction of the parapet by shells.

Time of Breaching.—1*st, with* 16-*pounders and* 8-*inch howitzers.*

Guns or Howitzers.	Shot or Shells.	Time. Opening Revetment.	Time. Destroying Counterforts.	Time. Destroying Parapet.	Time. Changing 2 guns for howitzers.	Time. Total.	Remarks.
		h. m. s.	h. m. s.	h. m. s.	h. m. s.	h. m. s.	
4 guns	270 shot	5 37 5	...	...	...		Distance from muzzle of gun to scarp 21·40 metres; excavation 22·75 metres wide, 4 metres high, 2·2 metres thick at base, and 1·42 metre at cordon.
...	36 shot	...	0 50 0	...	...		
2 howitz. & 2 guns	40 shells	...	...	1 0 0	...		
...	...	...	...	...	2 0 0		Total excavation 164·91 metres. The average rate of firing was 5′ per shot. The shells were partly fired experimentally, to ascertain the proper charges.
						9 27 3 or 9½ hours.	

The work of the guns was 1^m cube in 2′ 3″. After the firing of round shot had ceased, the breach, though still steep at the crest, was ascended by 30 gunners in line at a trot.

The shells perfected the breach,—those fired from the guns produced little effect, as they broke against the sand when fired with a charge sufficient to insure penetration.

The charges of 1^k to $1^k.50$, the shells from the howitzers penetrated 1^m, and being loaded with 2^k, produced by explosion entonnoirs which rapidly brought down the parapet.

To insure success, the fuzes must be filled with composition, and sunk well into the eye of the shell.

2nd.—Time with 24-pounders and 8-inch howitzers.

Guns or Howitzers.	Shot or Shells.	Time. Opening Revetment.	Time. Destroying Counterforts.	Time. Destroying Parapet.	Time. Changing 2 guns for howitzers.	Time. Total.	Remarks.
		h. m. s.	h. m. s.	h. m. s.	h. m. s.	h. m. s.	
4 guns	195 shot	4 3 45	...	...	...		Distance from muzzle of gun to scarp 31·9 metres. Excavation 21·66 metres wide, 4 metres high, 1·81 metre mean thickness. Total excavation 156·81 m.
...	38 shot	...	0 50 0	...	...		
2 8-in. howitz.	18 shells*	...	...	1 0 0	...		* These were shells from the howitzers alone. The shells from the 24-prs. were ineffective, as they could not be fired with a charge sufficient to insure penetration.
...	...	...	...	...	2 0 0		
						7 53 45 or 8 hours.	

The work of the guns was 1^m cube in 1′ 33″. As with the 16-prs., the breach, though steep at its crest, was practicable at the close of gun-firing. The number of shots fired, and the times of effecting the breach, being nearly in an inverse proportion to the weight of the shot, viz., 22 to 16, the total weight of metal and powder fired will be nearly the same; and, in consequence, the advantages of the 24-prs. over the 16-prs. will be that of diminished time with an increased distance,—the 16-prs. having been $21^m\cdot40$, and the 24-prs. $31^m\cdot9$ from the scarp.

These experiments, affording an accurate estimate of the possible working power of guns and howitzers when used under proper conditions, the more those conditions are departed from, whether from deficient skill or unfavourable circumstances, the less will be the effect produced, and the greater the time occupied.

The elements of efficiency are, the force of penetration of the projectile when it arrives at the wall, and the accuracy with which it is directed to a particular point or line.

The first of these will in round shot diminish with the distance of the battery (as the charge continues the same), but in shells discharged from howitzers it may be preserved undiminished by augmenting the charge, originally reduced to keep the shells from breaking against the parapet.

The amount of diminution from increased distance may be estimated either from the Table of Terminal Velocities, calculated by Colonel Piobert, or by direct reference to the Tables of Penetration given in this article.

Referring to that of penetration in masonry.

at 25 metres a 24-pr. shot, with a charge of $\frac{1}{2}$, penetrates 0·650 metre.
300 „ „ „ „ 0·530

0·120

therefore in 275 metres, or 300 yards nearly, the penetration has diminished nearly $\frac{1}{5}$th.

The penetration will therefore at the distances of 27 and 328 yards be respectively as 5 to 4; and as the diameter of the base of the conical portion of the excavation made by the shot varies also with the penetration, the actual effect of the firing, in making either the horizontal or vertical sections at those distances, will be as 5^2 to 4^2, or 25 to 16:* hence the time of effecting the first portion of the breach will be augmented more than one-half by the increase of distance alone.

With the French 16-prs., fired with a charge of $\frac{1}{2}$, the results will be as follow:

at 25 metres, or 27 yards, the penetration is	. . . . .	0·570
300 ,, 327 ,, ,,	. . . . . .	0·445

therefore in 275 metres, or 300 yards, the penetration has diminished 0·125 or between $\frac{1}{4}$ and $\frac{1}{5}$; and the actual effects on making the sections will be between the proportions 25 to 16, or 16 to 9; and the time will be increased between $\frac{1}{2}$ and $\frac{2}{3}$ by increased distance.

The second element, or the comparative accuracy of firing at different distances, requires yet to be based on experiments.

In the 'Aide-Mémoire d'Artillerie,' 1844, page 412, it is stated—"The number of shots striking a target 1 metre square at 600 metres, or 654 yards, is in 100—for 24-prs. 7; for 16-prs. 6; for 12-prs. 5; for 8-inch howitzers 4; for 6-inch howitzers 5:" from which it is evident how greatly the efficiency of breach firing must be diminished by increased distance, the shots striking over a large surface, and breaking up the wall into small fragments, rather than bringing it down in masses.

It was doubtless this system of pounding the wall which rendered the earlier formation of breaches so tedious; and the more irregular the firing, the nearer will the modern approach to the ancient practice in character.

At 300 metres, or 327 yards, if one-half of the shot, or 50 per cent., and one-third of the shells, be supposed effective (and these are probably very high proportions), the following would be the possible time of effecting breaches, under the most favourable circumstances.

With French 24-prs.—One gun to 5·41 metres or 5·9 yards running of scarp.

Opening revetment at short distances.	Increase for diminished penetration.	Increase for diminished accuracy of fire.	Changing guns for howitzers.	Destroying parapet at short distances.	Increase for diminished accuracy of fire.	Total.
4h 53′ 45″	2h 26′ 52½″	7h 20′ 37½″	2h 0′ 0″	1h 0′ 0″	2h 0′ 0″	19h 41′ 15″

With French† 16-prs.—One gun to 5·69 metres or 6·20 yards running of scarp.

Opening revetment at short distances	Increase for diminished penetration.	Increase for diminished accuracy of fire.	Changing guns for howitzers.	Destroying parapet at short distances.	Increase for diminished accuracy of fire.	Total.
6h 27′ 5″	3h 13′ 32½″	9h 40′ 37½″	2h 0′ 0″	1h 0′ 0″	2h 0′ 0″	24h 41′ 15″

* If the fall of the masonry depended exactly on the total effect of the shot *in all directions*, the ratio would be as the cubes of the penetrations. It has been shown that with guns of different alibres the times are nearly inversely as the weights of the shot, or with 16 and 24-prs. as 22 to 16. These numbers, if examined, will be found more nearly proportionate to the squares than to the cubes of the penetrations; and in like manner with guns of equal calibre, but at different distances, the times will vary in a proportion nearly corresponding to the squares of the penetrations.

† The French 16-pr. shot being equivalent to a shot of 17$\frac{5}{8}$ lbs. English, all the results of that description of gun may be applied to the English 18-prs.

Before an enemy, the difficulties and casualties attendant upon the opposing fire will greatly augment these periods, often to two or three times the amount.

These numbers may, however, when there is convenient space and an abundant armament, be diminished by the use of more guns, as appears to have been the case at Ciudad Rodrigo, where the proportion was one gun to 5 feet of scarp, instead of one to $18\frac{1}{2}$, as at Metz; and this will account for the comparative rapidity of forming the breach in that siege at an increased distance, independently of the inferiority of the masonry.

If these principles be applied to still further increased distances and to diminished charges, as in Ricochet Firing, it will be evident that the destruction of masonry traverses must be tedious, the force of penetration being diminished to about a third, and the inaccuracy of firing augmented in a large proportion.

Earthen traverses will be best destroyed by shells from howitzers; but, although the force of penetration will not vary so much with this arm, the uncertainty of fire will be augmented in a still greater ratio.

These considerations may suggest some useful remarks both as regards Ricochet Firing, and the construction and arrangement of Traverses, but they can be best noticed under their respective heads.

SMALL ARMS NOW IN USE.

The following are some of the results of numerous experiments carried on in 1858 *with the Enfield Rifle and the usual bullet and charge.*

Materials fired at.	Greatest penetration in inches at	
	200 yds.	20 yds.
Light sandy earth, lightly rammed . .	17·″	19·″
Elm boards, laid close together . . .	4·	4·
Elm, solid, *with* the grain	—	6·25
Oak, solid, *across* ,,	2·5	2·75
,, ,, *with* ,,	—	3·0
,, planks, *across* ,,	4·	4·
Ash planks, together . .	3·	3·
,, solid, *with* the grain .	—	4·
Beech planks, *across* .	3·25	—
,, solid, *with* the grain	—	4·
Pine boards, together .	11·5	14·5
,, solid, *with* the grain	—	14·
Sand-bags, filled with light earth and built up .	10	11
Gabions, viz. brushwood, Tyler's, Jones's, and the Sebastopol. .	none passed through.	

Materials fired at.	Greatest penetration in inches at	
	200 yds.	20 yds.
Fascines, just made, of green wood. . .	all through and into earth 6″	8″
Sap roller, usual size, (through first side only)		9″
Rope mantlet, 17 lbs. to square foot . .	proof	—
Steel plate mantlet, 9 lbs. per foot, $\frac{1}{8}$″ thick . .	proof	—
Steel plate mantlet $\frac{1}{4}$″ thick . . .	—	proof at 50 yds.
Iron boiler plate, $9\frac{5}{6}$ lbs. per foot, $\frac{1}{4}$″ thick . .	not proof	—
Homogeneous plates (Shortridge & Co.), A_2 $\frac{3}{16}$″, $7\frac{5}{12}$ lbs. per foot .	proof	proof
Homogeneous plates, B_2, $\frac{3}{16}$″, $8\frac{1}{3}$ lbs. . .	proof	proof

The Lancaster carbine gave slightly less penetration than the Enfield, and with both arms steel-pointed bullets gave an increased effect.

ARMSTRONG AND OTHER GUNS.

In the attack and defence of works close to the sea, guns of larger calibre, as the 56- and 68-pr., may be used, and then, as at Sebastopol, it is found that the ordinary thickness of earthen parapet (18 feet) is not sufficiently proof.

No complete tables have yet been given of the penetration obtained by the use of Armstrong guns, but it is undoubtedly far beyond that of the ordinary smooth-bore ordnance. From one set of trials lately carried on with the 40- and 82-pr. guns, and the 7-inch howitzer, carrying a 100lb shell, it appears that, firing at a distance of over 1000 yards, at very solid compact brickwork, with charges respectively of 5, 10, and 9lbs., the penetration of the 40-pr. and 7-inch was about 4 feet to 4′ 6″, and of the 82-pr. above 7′ 6″. A breach 20 feet wide was obtained by expending less than 3000lbs. of iron and 520lbs. of powder; while with the old 24-pr. guns of 50 cwt. the same result would have required above 42,000lbs. of iron and 14,000lbs. of powder, for a range of only 500 yards. The distance also at which the breaching battery was placed, would prevent the enemy's riflemen from stopping the besiegers' fire, up to the time of actually taking the work.—C.R.B.

Plate I. **PETARD.***—The petard, which formerly was part of the equipment of an army in the field, for the purpose of bursting open gates, has of late years been in disuse, and bags or cases of powder have been substituted for it.

The petard was of brass, and cast in a bell shape. It was fastened to a bed of elm plank, 3½ inches thick, having on the reverse, or under side, a wrought-iron plate, one-quarter of an inch in thickness. In the breech there was an aperture for the fuze, which was connected to the petard by means of a brass holder.

Four men were employed to carry the petard, and rings were placed at the angles of the bed for this purpose. A fifth ring was fastened to the upper side of the bed, as a means of connecting it to the gate intended to be destroyed, into which a hook was screwed to support it. The bed of the petard was still more firmly secured to the gate by means of screws from 6 to 8 inches long.

Two legs, or struts, were attached to the petard bed; they were between 4 and 5 feet long, and 4 inches in diameter at the bottom, or thicker end.

	Cwt.	qrs.	lbs.
The weight of the petard, with its fuze and bed, was . .	2	2	12
,, legs	0	1	16
,, screw-hooks	0	0	5
Total weight . .	3	0	5

The objection to the petard was, that on being fired with the full Service charge of 11 lbs. of powder, it was liable to burst, and the men of the party using it were exposed to injury from the splinters.† Bags of powder are not open to the same

* By Colonel (now Lieut.-General) Sir Frederick Smith, K.H., R.E., F.R.S.

† General Sir Charles Pasley, K.C.B. (then Colonel Pasley), in testing the relative efficiency (in the year 1825) of the petard and the powder-bag, had recourse to the following experiments:

Two pairs of palisade gates were formed, to one of which a bag containing 50 lbs. of gunpowder was attached, and to the other the petard loaded with the usual Service charge of 11 lbs. of gunpowder.

The bag was fastened by a hook to the centre of the gate. The explosion fully succeeded in blowing open the gates; that half to which the bag was suspended was thrown completely back: the effect upon the other half would have been similar, had not the bottom of the gate struck against the ground, which stopped it; but the gates were thrown entirely open, and the result was all that could have been desired.

The petard was suspended by a bolt from the top of the gates, so as to bring the centre of the petard opposite to that part where the iron swing bar was fastened, and the two legs were placed so as to ease the weight from the bolt. The fuze was lighted, and the charge exploded, bursting the petard into several pieces, while the effect was only that of breaking a hole through the gates of about 4 feet wide, for they were not even thrown open, and that half of the gate which was bolted at the bottom was not forced from its fastenings.

Parts of the petard bed were thrown to a considerable distance. One piece of the petard,

objection, and they have the advantage of being more easily procured, and much more portable.

Bags of powder may be successfully used either to blow open gates or to form breaches in stockades, or even in thin enclosure walls; and the efficacy of this means of overcoming such defences will be best understood from the records of some experiments conducted at the Royal Engineer Establishment at Chatham, with a view to ascertain the requisite charges, and the best mode of applying them under various circumstances.

Report of an Experiment in blowing open a pair of palisade gates with a bag of powder.

Experiment No. I.

The gates used for this experiment were of oak (each gate being 8 feet high by 5 feet wide). They were of triangular scantling out of 4-inch oak, cut diagonally in halves. Two posts, of about 10 inches in diameter and 15 feet long, were planted 3 feet deep in the ground, and the gates were connected with them by means of three pieces of stout scantling, placed across at the top, bottom, and centre, and spiked securely to the posts, as well as to the palisades of the gates. A strong strut was also fixed against each post, and another against the bar, which extended across the centre of the gates.

The charge used on this occasion was 50 lbs. of powder. It was contained in a bushel sand-bag, tarred and sanded over; a loop of half-inch rope was attached, for suspending the bag. On one side of the bag, near the bottom, a small collar of stout canvas was sewn, so as to stand out about 6 inches, as a precaution against the fire communicating to the charge before the fuze should be burnt out. A piece of Bickford's fuze 2 feet in length was used in firing the charge, one end being pushed through the collar into a hole made in the sand-bag.

By the explosion both gates were blown open and destroyed, and the posts were knocked down. Some of the pieces of the gates were thrown upwards of 150 yards to the rear, and several huts in the immediate neighbourhood were partly unroofed.*

Report of an Experiment in breaching stockades with bags of gunpowder.

On the 16th April, 1840, a preliminary trial was made of a bag containing 60 lbs. of powder, laid on the ground, close against two beams of African oak (old ship-timber, obtained from Her Majesty's Dockyard), the scantlings of which were 13 inches by 11 inches, and 11 inches by 8 inches. The beams were sunk 3 feet in the ground, and were $3\frac{1}{2}$ inches apart. A piece of Bickford's fuze 4 feet long was attached to the bag. The explosion blew both timbers out of the ground, shattering one and splitting the other.

Experiment No. 2. Plate II.

On the 21st April, 1840, a strong stockade, 21 feet in length, composed chiefly of English and African oak, obtained from the Dockyard, was erected within a few feet of high-water mark, on the glacis in front of the left bastion of the works at St. Mary's Creek.

A trench 21 feet long, 2 feet wide, and 3 feet deep, having been made, the timbers were planted in it at intervals, and the soil, a stiff clay, was well rammed about them.

Five bags covered with water-proof composition, and each containing 60 lbs. of gunpowder, were prepared, and two of them had a Bickford's fuze 3 feet long attached.

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weighing $11\frac{1}{2}$ lbs., was thrown a distance of 60 yards, and a part of the bed was blown to the distance of 126 yards; several smaller pieces were also found within that radius. The two legs were thrown 20 feet to the right and left of the gates, and a great part of the iron plate from the bottom of the bed was projected several yards.

The thickness of metal of the petard was found to be $1\frac{1}{4}$ inch at the breech, and 1 inch next to the bed.

* This and the following experiments were tried when the Royal Engineer Establishment was under the direction of General Sir Charles Pasley, K.C.B.

On the 25th April, 1840, an Officer carrying a slow-match, with five men carrying the powder-bags, advanced to the stockade. No. 3 first deposited his bag on the ground close against the middle of the stockade. Nos. 2 and 4 placed theirs on the right and left of No. 3, the ends of the bags touching. The bags Nos. 1 and 5, with fuzes attached, were immediately placed over the centre of and upon the first three bags. All the carriers excepting one, who remained to bring the ends of the fuzes together, retired. The Officer immediately lighted the fuzes. The explosion threw up an immense volume of smoke, with numerous fragments of timbers, some of which went nearly across St. Mary's Creek, a distance of 123 yards. As soon as the smoke dispersed, a most perfect breach, 12 feet wide, became perceptible. The stoutest timbers were shattered to pieces, and a crater was formed the whole length of the breach, 9 feet wide and 3 feet deep.

The stockades adverted to in the following experiments were erected between the years 1842* and 1850, on the practice ground of the Royal Engineer Establishment, on the left of Chatham Lines; and the timbers, sometimes of oak, and sometimes of fir, were generally 12 feet long, and about 12 inches square in their cross section. They were placed in close contact in a trench 3 feet deep, and were connected together by one or more ribands firmly spiked to them. After being planted in the ground, the earth that had been excavated in forming the trench was carefully rammed round the timbers, so as to give the construction every possible degree of firmness and solidity.

The charge in each case was placed in contact with the timbers of the stockade, and contained in tarred sand-bags; and, when not stated to the contrary, it was fired by means of Bickford's fuze.

Experiment No. 3. Plate III.

A stockade of about 24 feet in length was constructed, for the purpose of being breached by means of gunpowder, on the 25th October, 1842.

It was composed of Baltic fir, procured from Her Majesty's Dockyard.

The timbers were connected by a riband of English oak, 6 inches square, to which they were firmly spiked at the bottom of the trench.

The charge of gunpowder used to form the breach was 240 lbs., contained in four tarred sand-bags. The bags were placed in two tiers; three on the lower, and one on the upper tier. A piece of ½-inch hose, filled with gunpowder, and 4 feet in length, was fastened to the middle bag of the lower tier for a train, and a piece of portfire 2 inches long was attached to it: a perfect breach, about 12 feet wide, was the result of the explosion.

Experiment No. 4. Plate IV.

This stockade was 22 feet long, and composed of Baltic fir. The timbers were connected together by a riband 6 inches by 4 inches, placed at the bottom of the trench.

The charge consisted of only 60 lbs. of powder, contained in a tarred sand-bag, having 2 feet of Bickford's fuze attached to it.

The powder-bag was placed on the ground, and a bushel bag filled with sand was laid on the top, and one at each end, as tamping: the explosion formed a practicable breach of about 6 feet in width.

In the month of December, 1845, a stockade was constructed about 30 feet in length, and the upright timbers connected together by three ribands; one on the inside near the top, and two near the bottom, of which latter, one was on either side of the uprights: the earth was rammed on both sides of the uprights to the level of the ground.

* When Sir F. Smith had succeeded Sir Chas. Pasley at Chatham as Director.

For the purpose of ascertaining the minimum charge for destroying a stockade of the strength above described, the following experiments were tried on the 15th and 21st January, 1846.

Experiment No. 5. An attempt to breach was made by firing a charge of 30 lbs. of powder, contained in a bag, and suspended to the stockade opposite to the upper riband, and 3 feet from the north end. The effect was merely to dislodge a few of the timbers from their upright position.

Experiment No. 6. A second charge of 30 lbs. of powder was next slung on a nail, at a height of 3 feet from the ground, and 6 feet from the north end. On the explosion of this charge, it was found that one timber only was broken through, and a few others slightly shaken.

Experiment No. 7. A similar charge was placed at the distance of 3 feet from the southern extremity of the stockade, on the ground, and touching the timbers. A crater 2 feet in length, 12 inches in depth, and 15 inches wide, was formed by this explosion, and seven timbers were started, one being broken short off close to the ground.

Experiment No. 8. A fourth charge of 30 lbs. of powder, also contained in a bag, was laid on the ground at 6 feet from the southern end of the stockade. Two bushel bags of earth were laid upon the bag of powder, and two were placed in front of and in contact with it. On firing the charge, it formed a narrow breach in the stockade by driving two of the piles out of the ground, and breaking another asunder, besides dislodging several of the timbers adjoining.

Experiment No. 9. A charge of 70 lbs. of powder, and another of 50 lbs., were placed on the ground with an interval of 5 feet between them, and both touching the stockade near the middle of its length. Four bushel sand-bags, filled with earth, were applied, as in the preceding experiments, upon and against each charge.

In this instance a spacious breach was made, and some of the piles were thrown upwards of 50 yards from the stockade; and from these experiments it may be concluded, that from 60 to 70 lbs. of powder, properly loaded with bags of earth, will be a sufficient charge for producing a practicable breach in a stockade of this strength. The extent of breach required will of course regulate the number of charges to be used.

Experiment No. 10. Plate V. 6th September, 1846.—Major Marlow, Commanding Royal Engineer in New Zealand, having sent to England drawings and a description of one of the 'Pahs' constructed in that country by the Chief, Heki, a part of a stockaded work, nearly on that plan, was erected in August, 1846, on the left of Chatham Lines, with a view of ascertaining by experiments the best mode of breaching it by bags of powder.*

The external fence consisted of a frame-work of double posts, 6 inches by 10 inches, firmly spiked together; placed at intervals of 5 feet 3 inches, and connected by two ribands above ground, 12 inches wide and 4 inches thick, and by one riband under ground, of the same dimensions. To the two upper ribands, fascines were fixed, extending to within 2 feet of the ground, to represent the green flax used in the same position in 'Heki's Pah.'†

The second enclosure consisted of oak timbers, also 10 inches square, placed close together, and connected by an underground riband 12 inches wide and 4 inches thick.

The upright timbers in both enclosures were 9 feet above ground, and 3 feet in the ground.

An interior enclosure, or keep, 10 feet 9 inches distant from the last described, was

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* The deviations are improvements on the rude construction of the New Zealanders.

† See article 'Pah,' vol. ii.

formed of oak timbers, fixed 2 feet 6 inches in the ground, and 9 feet 6 inches out of it. The timbers were 12 inches square, and also placed in close contact; they were united by one riband above ground, and one under ground, each 12 inches wide and 4 inches thick. The communication to the interior of the keep, from the middle enclosure, was formed by means of an underground gallery, 4 feet 6 inches by 3 feet, driven within and parallel to the stockade of the keep, at the distance of about 3 feet 3 inches, as a place of security for the garrison from the fire of the enemy's artillery. The interior and the centre enclosures were loopholed.

The earth was well rammed round the timbers.

Plate V. On the 4th of October, 1846, the pah was attempted to be breached by the following process: a tarred sand-bag, containing 100 lbs. of gunpowder, was passed underneath the fascines of the outer enclosure, and lodged in the position marked A, in contact with the stockade G H of the centre enclosure, and two bushel bags filled with earth were placed upon it as shown in drawing (F).

At the distance of 3 feet 6 inches from this charge, another of 100 lbs. (B) was also placed on the ground, and in contact with the same stockade, but on this charge no sand-bags were placed. The two charges were fired simultaneously, and a practicable breach, of about 8 feet in width, was formed in the outer and centre enclosures, the débris of the one being thrown outwards, and of the other inwards. The inner stockade was not injured: another bag, containing 150 lbs. of powder, was afterwards placed in contact with it, in the position marked C, but it was not weighted with bags of earth. On being fired, a breach was formed of about 6 feet in width.

Experiment No. 11. 1st December, 1846.—It being considered necessary to have further experience in breaching double stockades, another portion of a stronghold similar to 'Heki's Pah' was constructed.

A charge of 120 lbs. of powder, contained in two tarred sand-bags, was lodged against the centre line of timbers. Four bushel bags were filled with common earth, and two of them were placed on the top of the charge, and one at each end.

The result of the explosion was the destruction of about 10 feet of the centre and outer stockade, and pieces of both were thrown upwards of 200 feet from the line in which they had been placed: the timbers of the inner enclosure or keep were merely disturbed from their upright position, but they were not thrown down or broken.

Experiment No. 12. 8th June, 1847.—A double stockade was erected for the purpose of training the Embodied Pensioners (then about to proceed to New Zealand) in the mode of capturing such works, and also to obtain further information on the subject.

This stockade was composed of oak timbers, 13 feet long, and averaging 13 inches in thickness and breadth, placed in trenches 4 feet deep, so that 9 feet were above ground.

There was an interval of 4 feet 4 inches between the two lines of stockade.

The timbers of each line were united by two ribands, 12 inches wide and 4 inches thick, of pitch pine plank. The upper riband was placed at the distance of 7 feet from the ground, and the lower one with its upper edge flush with the surface.

The two lines of timber were joined together at their extremities by two cross ribands of the same width and thickness as the longitudinal ribands, to give that degree of general stiffness which would be found in a complete stockade enclosure.

A charge of 200 lbs. of gunpowder, in four bags, was lodged in four layers at the bottom of the outer line of stockade, the lower bag resting on the ground.

Two sand-bags filled with earth were placed on the top of the upper bag of powder, besides two in front of the charge, and one at each end of it, in order to confine the action of the gunpowder as much as possible to the stockade.

A piece of Bickford's fuze, 6 feet in length, was attached to one end of the central bags, 6 inches of it being inserted within the bag.

The fuze was ignited by slow-match, and the explosion of the whole charge was simultaneous. A breach was formed in both lines of stockade. The width of the opening in the outer line measured 9 feet 6 inches, and that of the inner line about 5 feet 6 inches.

Experiment No. 13.

9th June, 1847.—The double stockade breached this day was formed in the same manner as that destroyed on the 8th June, the only difference being that the interval between the two rows of stockade was in this case 3 feet 5 inches, instead of 4 feet 4 inches.

It being desirable to ascertain whether both lines of stockade might be breached at the same time by 200 lbs. of powder *without confining the charge with bags of earth*, none were used on this occasion.

The company of Embodied Pensioners for service in New Zealand were practised in advancing to the face of the stockade, covered by sap rollers,* having in the rear of the centre sap roller a truck containing the charge of gunpowder.

On reaching the foot of the stockade, the sap rollers remained in their position, and the truck was moved into an interval between the two rollers. On tilting up the truck, the bags of powder slipped off and lodged at the foot of the stockade. This was effected without difficulty, and there is every reason to presume that, on actual service, men advancing to lodge the charge might be thus protected against the musketry fire of the garrison, when the situation was favourable to such a proceeding.

By the explosion a breach of 6 feet 6 inches was made in the outer line, and one of 4 feet in the inner line.

Experiment No. 14.

11th August, 1848.—A stockade was erected on the causeway adjoining the ditch of St. Mary's Hornwork.

A breach was effected, sufficient for the passage of about twelve men abreast, by the explosion of two charges of gunpowder, each consisting of 100 lbs., and separated from each other by an interval of 6 feet. The charges were placed in water-proof bags, and a bag of earth was laid on the top, and one at either end of both charges.

The conclusion to be drawn from the various experiments above described is—

1st. That any single line of stockade, when the timbers do not exceed 14 inches in thickness, may be breached by a charge of 100 lbs. of powder placed on the ground and in contact with the timbers; and that when bags of earth are placed upon and against a charge, its effect on the stockade will be greatly increased.

2nd. That a double stockade may be breached by one charge of 200 lbs. of powder lodged against the outer line of timbers, when the interval between the rows does not exceed 3 feet 6 inches.

3rd. That when there is reason to presume that the interval between the rows of timber is much greater than 3 feet 6 inches, the breach in the two lines must be produced by two distinct explosions.

The chief difficulty in all attempts to force an entrance into defensible works of the description under consideration, is the placing of the charges without exposing the party employed in this critical operation to great risk.

Even when the attack of a stockade is made at night, it may be presumed that some loss would be sustained by the assailants if they advance to the stockade without having any cover, whatever may be the caution with which they approach it; and therefore, as a security against failure from casualties, it would be desirable to attempt to attach powder-bags at various points of the enclosure.

* Mantlets of iron plate, $\frac{3}{16}$ inch thick, mounted on a light frame with wheels, would be far preferable for this purpose.—*Ed.*

If the attack be made by day, the mode of approach must be determined by local and other circumstances; probably the show of an escalade, under a heavy fire of musketry and artillery, may enable the Engineers to lodge their powder-bags, &c., at the foot of the stockade; but where circumstances will admit of waiting for the construction of sap rollers, and the ground is favourable for pushing them forward, they may be used as a tolerably safe screen for the assailants.

When a town gate has to be breached, it would be unsafe to depend upon a smaller charge than 200 lbs. of powder, and it should be weighted with three or more bags of earth, as in all probability the gates would be strengthened by cross-bars and struts. In no case does it seem desirable to suspend the charge above the level of the ground.

Bags of powder may also be used in breaching thin walls of brickwork.

The following experiments were tried at the Royal Engineer Establishment, to ascertain the quantity of powder required to form such a breach, and the best mode of applying the charge for that purpose.

3rd October, 1826.—Experiments were made on two brick walls, each 8 feet long, 5 feet high, and 2 feet 3 inches thick, which had been built in the month of November, 1825, or eleven months previous to the experiments.

Experiment No. 1.

To the back of one of these walls, two bags each containing 15 lbs. of powder were suspended at the height of 12 inches above the ground. These charges, which were 4 feet apart, and equidistant from the centre, were fired simultaneously.

After the explosion, the wall appeared to be considerably injured. Those parts of it immediately opposite to where the charges were placed, were forced out to a distance of 1¼ inch, and presented an appearance similar to what would probably be produced by the blow of a battering-ram.

Experiment No. 2.

In the second experiment, two charges each of 30 lbs. of powder were applied to the back of the other wall, on the level of the surface of the ground, 4 feet apart, and equidistant from the centre. A quantity of earth of about 4 feet 2 inches in thickness was heaped over the charges to create a resistance in the opposite direction to the wall.

The charges were fired simultaneously, and the effect was the complete destruction of the wall.*

Results of Experiments in the demolition by gunpowder of walls built of brickwork and cement, between the years 1848 *and* 1850.

Experiment No. 3. Plate VI.

Wall No. 1, of 9-inch work, 6 feet high and 6 feet long, with piers 9 inches square at the extremities. The depth of the foundation was 1 foot.

The charges in every case were placed on the ground near the centre of the wall.

The first charge, which was of 6 lbs. of powder, produced no visible effect.

The second charge was of 7 lbs., and the explosion cracked the wall at the bottom, very slightly, opposite to the charge.

The third charge was of 6 lbs. of powder, and was weighted with two bushel bags filled with earth. The explosion of this charge utterly demolished the wall.

Experiment No. 4.

Wall No. 2, similar in every respect to Wall No. 1.

The charge of 10 lbs. of powder was contained in two bags (one of 6 lbs. and the other of 4 lbs.). By the explosion, the wall was fractured at about half its height,

* In the record of this experiment, which appears to have been conducted under the orders of Major-General Sir Charles Pasley, by Lieutenant Renwick, of the Royal Engineers, it is stated that the mortar was "particularly bad," the wall having been built during the continuance of a severe frost.

besides which a dislocation was produced between the foundation and the remainder of the wall. The brickwork was generally so very much damaged that it was pushed over with ease by four men.

Experiment No. 5.

Wall No. 3, similar in every respect to Walls Nos. 1 and 2.

A charge of 10 lbs. of powder in one bag was applied to the foot of the face of the wall, and a bushel bag filled with earth was placed in front of and resting on the charge of powder.

The explosion produced complete demolition of the wall and piers.

Experiment No. 6.

Wall No. 4, of 14-inch work, 6 feet high and 6 feet long, without counterforts or piers.

The charge was of 10 lbs. of gunpowder, not weighted with bags of earth or sand.

The explosion produced no apparent effect on the wall.

Experiment No. 7.

The same Wall.—The charge the same as before (10 lbs. of powder), and placed in the same manner, but weighted with one filled bushel bag laid upon the charge.

The wall was cracked by the explosion, but was not very materially injured.

Experiment No. 8.

Wall No. 5, of 14-inch work, 6 feet long and 6 feet high, with piers at the extremities, 14 inches square. The depth of the foundation was 12 inches.

The charge of 8 lbs. of powder, weighted with two bags filled with earth, was placed at the foot of the wall, near the centre.

The explosion forced some of the bricks out of the bottom of the wall, which was cracked in such a manner as to be quite unfit for further experiments.

Experiment No. 9.

Wall No. 6, of precisely the same form and dimensions as Wall No. 5.

A charge of 20 lbs. of powder, not weighted, was placed as in the previous experiment.

By the explosion the wall was very much shaken, so that it might have been easily pushed over by three or four persons pressing against it.

Experiment No. 10.

Wall No. 7, precisely the same as Walls Nos. 5 and 6.

The charge was 15 lbs. of powder, weighted with three bushel bags filled with earth, each standing on end, one being placed at either extremity of the charge, and the third in front of it. The charge was lodged, as in the two former experiments, upon the ground near the middle of the foot of the wall.

By the explosion the wall was totally destroyed.

Experiment No. 11. Plate VII.

The enclosure wall of the fire-barns on the left of Chatham Lines is of good brick-work, 14 inches thick, with piers at intervals of 10 feet, and it is 10 feet high.

It was intended to breach this wall by two charges of powder, each of 60 lbs., to be placed 6 feet only apart; but by an error they were placed 10 feet apart, and the consequence was that two openings were blown through the wall, as shewn in the sketch, instead of one large breach being formed; both holes were large enough, however, to let men pass through.

It may be deduced from these experiments, that a 14-inch wall, however well built, may be breached by charges of 60 lbs. of powder, weighted with two or three bags of earth, the charges being not more than 5 or 6 feet apart.

Note.—Some interesting experiments were made at Chatham in September, 1850, under the direction of Colonel Sir F. Smith. A charge of 21 lbs. of powder was placed in a bag, three sides of which were of leather, the other of light canvas: the latter being placed against a stockade which was 6 inches thick, the charge was fired from the centre by means of a piece of Bickford's fuze, covered with gutta percha, and wrapped in a piece of tinfoil, being inserted into it. Another charge of 21 lbs. of powder was placed in a common canvas bag, and fired in the ordinary way against a similar stockade.

The former broke the stockade immediately above the bag.

The latter charge had no effect whatever.

The proposition appears to have originated with the Master-Gunner of Pendennis Castle, Mr. Copeland.—*Editors.*

PHOTOGRAPHY* has now attained to a position of such acknowledged usefulness in reference to many of the arts and sciences in which the Corps of Royal Engineers are professionally interested, that some notes on the subject may prove valuable to officers who have not had an opportunity of studying or practising it. So many excellent works, however, on photography have been already published, that it would be quite superfluous for me to enter at length into the chemistry or describe minutely the manipulations of the art: it will be sufficient if I refer my brother-officers to the best works on the subject, and confine myself to such practical hints as may be likely to aid in the selection of good serviceable apparatus, and in using the apparatus to the best advantage under the varying circumstances, as regards climate, &c., in which officers may be placed. And as this beautiful art is as yet but in its infancy, it should be borne in mind by those officers who have had any experience in the working of photography in foreign countries, that an account of the difficulties they have met with, and the means they have found most effectual in overcoming them, will be very valuable.

It is not probable that photography will ever be of much service on the field of battle, or in cases where very great expedition is necessary. Success in photography depends upon the favourable combination of so many minute circumstances connected with the state of the weather and the chemical agents employed, and also with the delicate apparatus and the manipulation, that it is not to be expected, in the present state of our knowledge of the art, that any good results should be obtained under the unfavourable conditions of hurry, dust, smoke, &c., inseparable from active military operations.

In reconnoitring hostile fortresses it is possible that photographs taken by means of some of the various "dry" processes may in some cases prove of service; but it is not probable that much assistance will be derived from photography in such cases on account of the exceedingly small scale on which distant objects are represented in a picture taken by means of the camera, even when the apparatus is of large size. And as the size of the apparatus increases, the difficulties connected with the practice of the art increase also in a very rapid ratio; it becomes also a more conspicuous object for the enemy's marksmen.

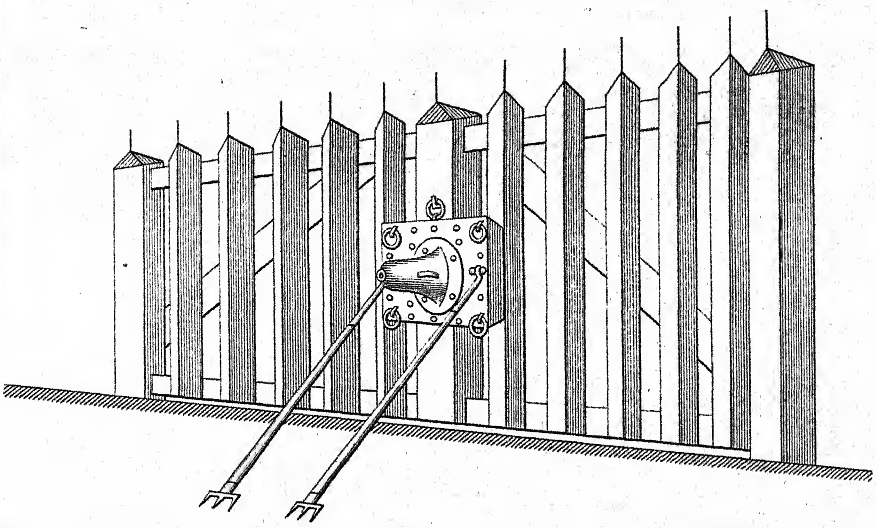
The uses to which photography has been found applicable in a military and scientific point of view, or to which it evidently may be made subservient, are briefly as follows, viz. :—

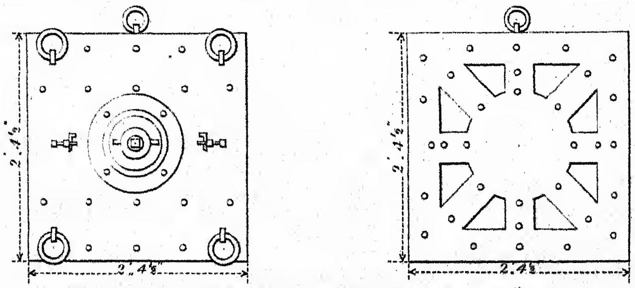
1. Obtaining exact records of the progress of public works in course of construction, which may take the place of those tedious "progress plans" too well known to most officers of the Corps; thus saving much valuable time and obtaining, with the minimum of labour and expense, absolutely truthful representations of the progress of the works.

2. Copying plans and maps, either on the same scale, or reduced or enlarged. This application of photography, first made use of on an extended scale by Colonel Sir H. James, Director of the Ordnance Survey, has lately been perfected under his direction by Captain A. de C. Scott and Corporal Rider, R.E., in the new process of photo-

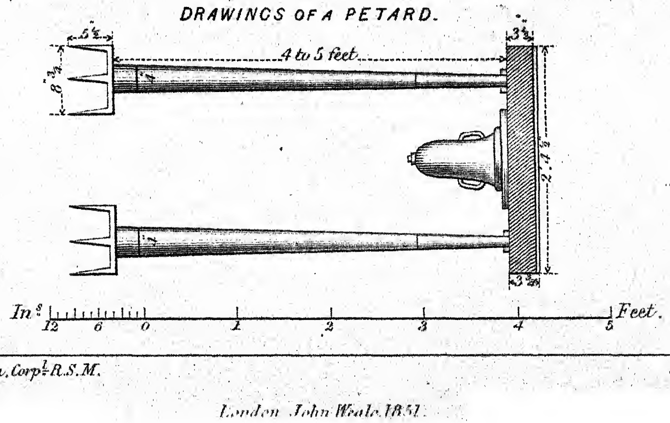
* By Captain Schaw, R.E.

DRAWING OF A PETARD *as applied to a Palisade Gate.*





DRAWINGS OF A PETARD.



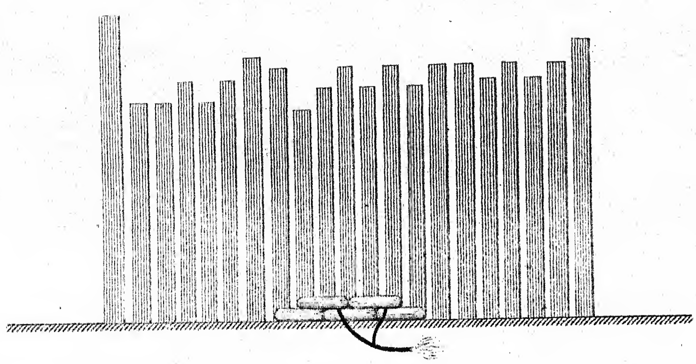
Drawn by A. Callaghan, Corp.l R.S.M. *W. A. Beever Sc.*

London. John Weale. 1851.

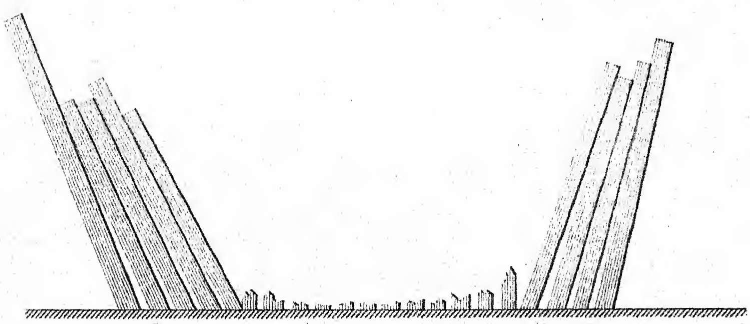
EXPERIMENT No. 2.

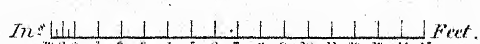
(With a charge of 300 lbs of Powder)

Stockade before the Explosion.



Stockade after the Explosion.





Drawn by J. Callaghan, Corp.l R.S.M.

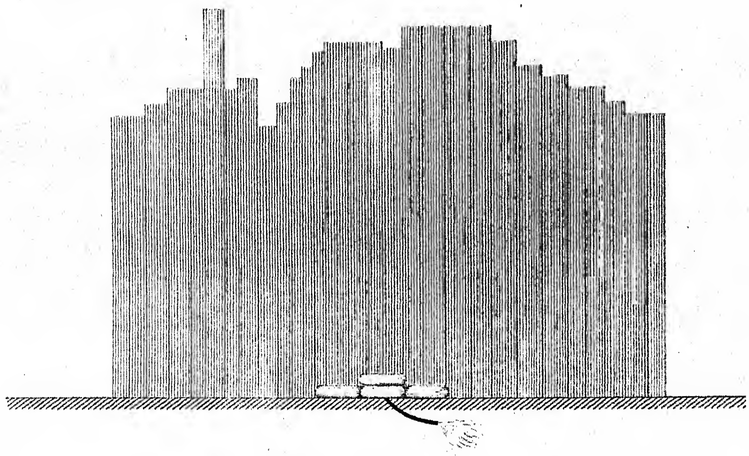
W.A. Beever Sc.

London. John Weale, 1851.

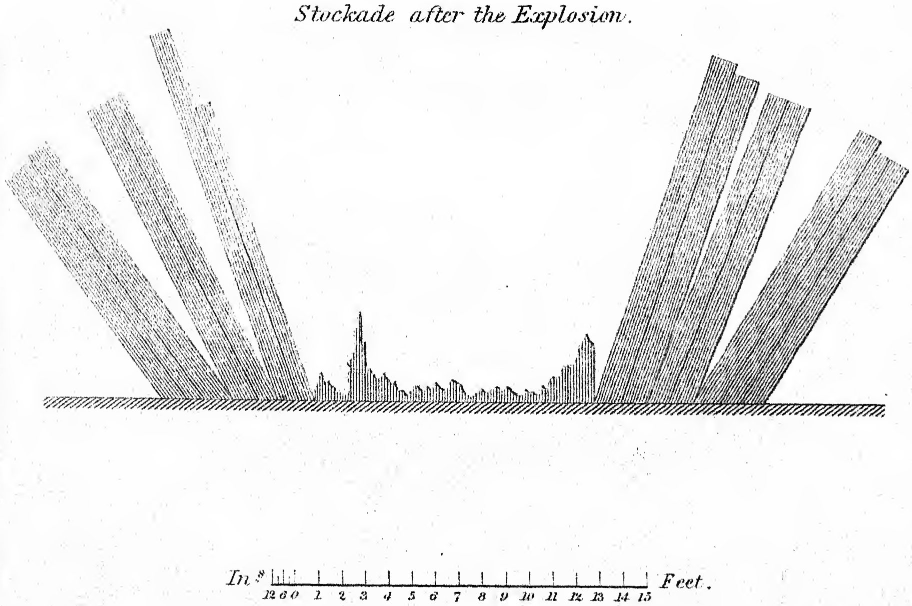
EXPERIMENT No. 3.

With a Charge of 240 lbs of Gunpowder.

Stockade before the Explosion.



Stockade after the Explosion.



Drawn by A. Callaghan, Corpl. R.S.M.

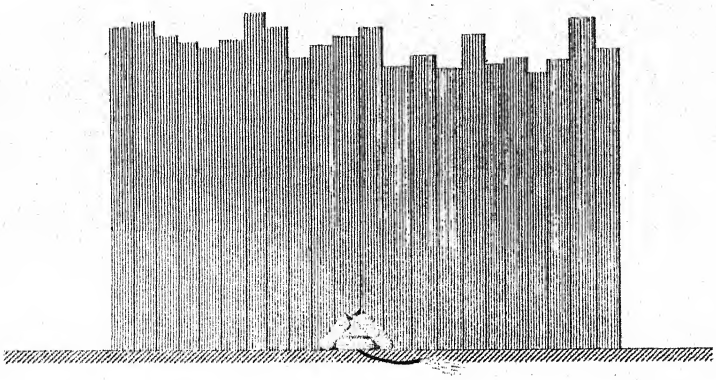
W. A. Beever, Sc.

London. John Weale. 1851.

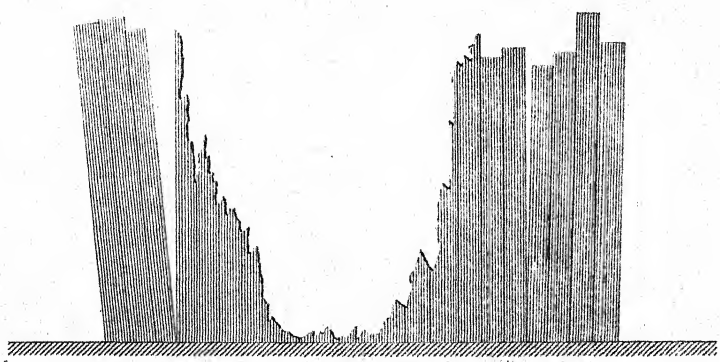
EXPERIMENT No. 4.

With a Charge of 60 lbs of Gunpowder.

Stockade before the Explosion.



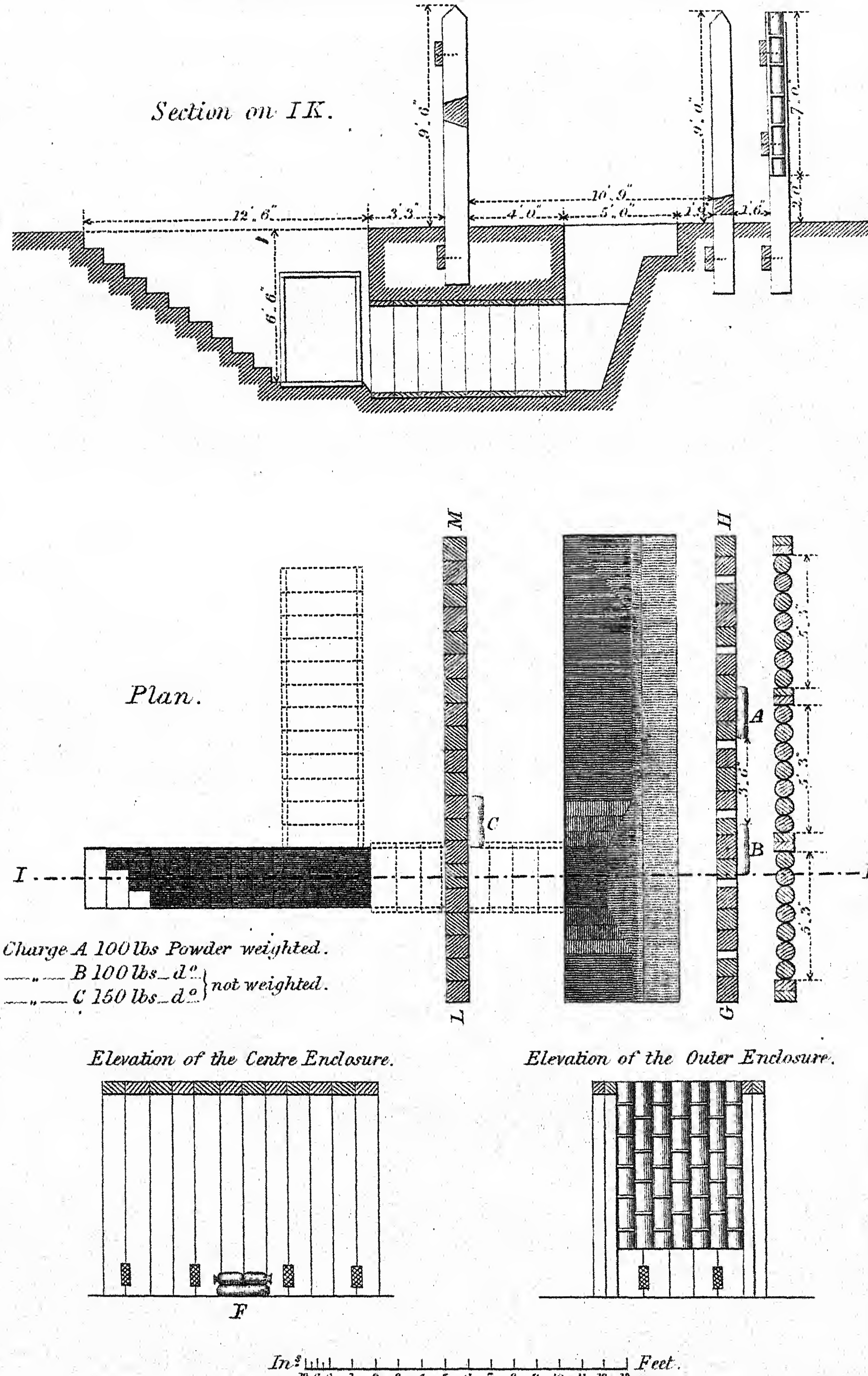
Stockade after the Explosion.



Drawn by A. Callaghan, Corpl. R.S.M.
W.A. Beever, Sc.

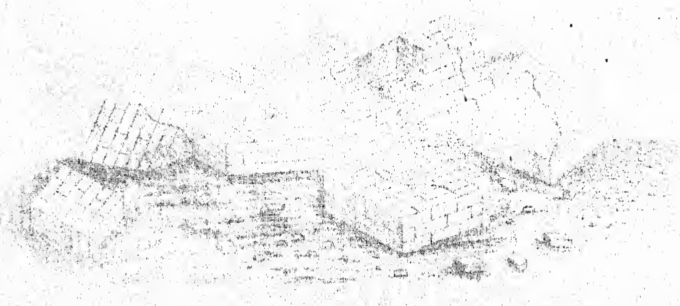
London, John Weale 1851.

DRAWINGS OF A STOCKADED WORK *similar to that Constructed by the New Zealand Chief "HEKI".*



Drawn by A. Callaghan, Corp.l R.S.M. W. A. Beever, Sc.

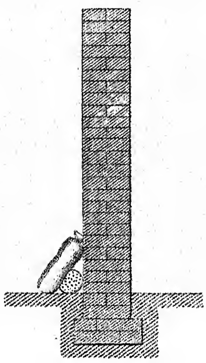
London. John Weale, 1851.



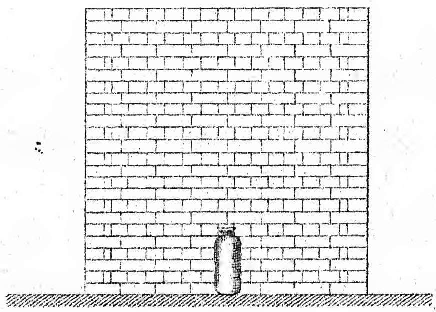
DEMOLITION OF BRICK WALLS.

Charge 6 lbs of Powder weighted.

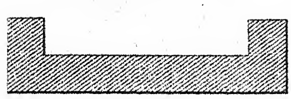
Section of Wall before the Explosion.

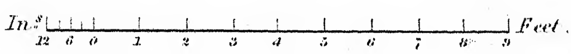


Elevation of Wall before the Explosion.

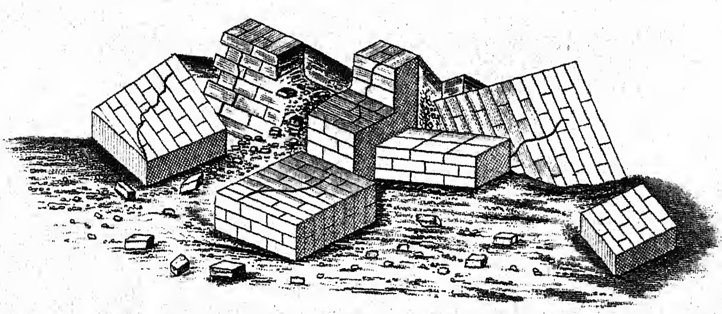


Plan of Wall.





Appearance of the Wall after the Explosion.

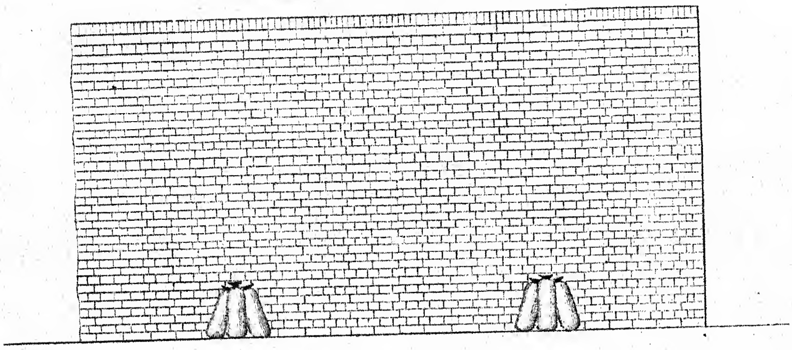


Drawn by A. Callaghan, Corp.l R.S.M.
W. A. Beever. Sc.
London. John Weale. 1851.

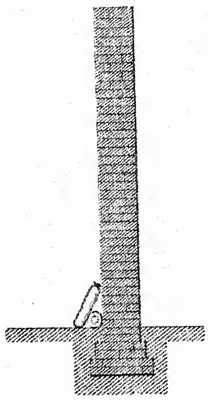
DEMOLITION OF BRICK WALLS.

With two Charges each of 60 lbs of Gunpowder.

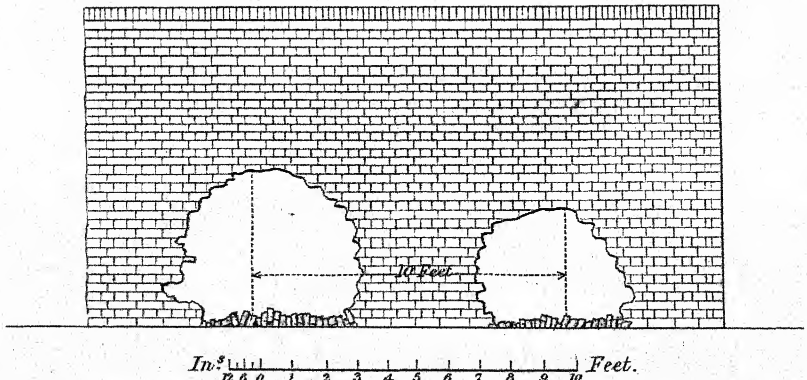
Elevation of Fire Barn Wall.



Section of Fire Barn Wall.



Elevation of Wall after the Explosion.



Drawn by A. Callaghan, Corpl. R.S.M. W.A. Beever, Sc.

London, John Weale, 1851.

zincography. Sir H. James will doubtless shortly publish full details of this most valuable discovery, which promises to be exceedingly useful to the Corps and to the public at large.

3. Obtaining minutely accurate pictures of architectural subjects of acknowledged excellence, to assist in designing new works and buildings; or of existing buildings to which additions or alterations are required, to enable the designer to adapt the new work to correspond with the old.

4. Preserving exact representations of failures in buildings from defective foundations or other causes, and thus possibly avoiding litigations with contractors after the defects have been made good.

5. Recording the effects of the explosion of gunpowder in different positions.

6. Recording the results of all sorts of experiments in mechanical constructions or new inventions, shewing their success or failure, and illustrating reports on the subjects.

7. Illustrating the methods of making military bridges, gabions, fascines, &c.

8. Shewing the correct positions for soldiers in their various drills, such as rifle drill.

9. In surveying boundaries of different countries, photographs of remarkable natural features of the country, which may either occur in the boundary line or be visible from certain points in it, will tend to fix the positions of the line with great certainty.

10. Obtaining portraits of remarkable persons and costumes of foreigners.

For amateurs, photographs of scenes, places, and persons which have interested them in the different countries they may have visited, must, in after years, prove deeply interesting both to themselves and to others, and will well repay the trouble and expense incurred in obtaining them.

The Photographic Processes Recommended to be Employed.—Of all the numerous different processes by means of which sun-pictures have been obtained, the one which has hitherto been found in every way the most satisfactory is the ordinary process of taking a negative picture on collodion, from which almost any number of positive prints on paper may be obtained. For very large pictures, where the rendering of minute details is not an object, the calotype or other process for taking negatives on paper may be preferred occasionally; but the very great difficulty of obtaining paper sufficiently *even* in texture and free from impurities, the long exposure in the camera which is necessary, and the still more tedious process of development required in all negative paper processes, together with the entire destruction of the picture resulting from the least failure in chemical cleanliness in the operations, have proved serious obstacles to success in this branch of photography. And even the great advantages which it possesses in the lightness and portability of the material on which the negative image is formed, and the power of dispensing with the dark tent, with all its paraphernalia, when taking views at a distance from the dark room, have not obtained for it more than a very few supporters among the multitudes who now practise the "black art." I shall therefore not further allude to any of the processes for obtaining negative pictures on paper, except to the waxed paper process of Le Gray, which, slightly modified, appears to have given the most general satisfaction. Some of the pictures obtained from waxed paper negatives, occasionally to be seen in our photographic exhibitions, nearly equal collodion pictures in the clearness of the details and the beautiful gradations of half-tone. In hot climates, when the stock of collodion has been spoiled (an accident that will occur sometimes), it may be worth while occasionally to use waxed paper as a substitute for it. I have therefore appended a description of a waxed paper process which has been found to succeed very well at Bombay. It is from the pen of Mr. H. Stanley Crawford, Secretary to the Bombay Photographic Society, and was published in the Photographic News, Vol. I., No. 18, August 5, 1859.

The remaining processes may be divided into dry collodion, properly so called, and the honey and oxymel, and other processes where the sensitive surface is coated with some preservative solution which remains moist for a considerable length of time, and in which the plates must be exposed while the surface still remains moist. Although very exquisite pictures may be obtained at some distance from the operating room by means of the latter class of processes, yet the very great care necessary in avoiding dust, &c., render them quite unfitted for military purposes. The dry collodion processes may be subdivided into those in which the collodion, either simply iodized, or mixed with some resinous substance, is sensitized, washed, and dried; and those in which the sensitized film of collodion is covered with some preservative agent, such as albumen, gelatine, gum, &c. A great variety of such processes are before the public, and nearly all of them have been tried with more or less success at this establishment; but our experience does not warrant me in recommending any one of them as a sure and simple process for plates of a large size. Good results have been produced by skilful operators with nearly all of these processes, yet failures are so frequent, and so difficult to account for, or to avoid, that it would seem as if the great desideratum of a simple and certain dry process has not yet been realized. A special collodion made with acids at a high temperature, and giving a "powdery" film which is porous and adheres strongly to the glass, appears essential for success with dry collodion.

All the dry collodion processes have given better results when small plates were used than in larger pictures; both because the small plates are more easily prepared, and because the light acts more powerfully on the sensitive surface in proportion as the lens has a shorter focus.

The time of exposure in the camera appears to be about the same for all the dry collodion processes, viz., about six times that required for a wet collodion plate, under the same circumstances, and with a moderately quick working collodion; but in regard to rapidity of development, the Fothergill and gum-arabic processes have a considerable advantage over the others, requiring not more than twice as long as wet collodion, while plates prepared by the other dry collodion processes are usually very tedious in development.

As regards all the "dry processes," however, whether on paper or glass, where the tent is not taken into the field and the picture is developed either at the end of a tour or in the evening of the day on which the view was taken, there is so much uncertainty about the results, and disappointment occurs so frequently when it is too late to repair it by exposing another plate, that, with all its inconveniences, the wet collodion process is very much to be preferred. If a failure does occur (as it often will) in working with wet collodion, it is apparent at once, and the operator can try again, and generally by patience and ingenuity he will overcome his difficulties, and not leave the subject he wishes to take a picture of until he has obtained a good negative.

The manipulations of the wet collodion process are so thoroughly described in "Hardwich's Photographic Chemistry," and in the numerous hand-books published on the subject, that I need not notice them here; but pass on to describe the apparatus necessary.

The Camera.—A good well-seasoned mahogany camera, brass-bound, with sliding body, is the most generally useful form; but, for portability, cameras are made to fold down flat by means of hinges in the sides, and these are much more durable than the still more portable form with an accordion body; the last mentioned form, however, is extremely light, and when provided with proper brass stays to prevent its being shaken by the wind, is sufficiently steady.

Accordion bodies are not to be recommended for hot climates, as insects eat the leather and destroy the camera. If the camera is required for copying drawings, &c.,

full size, it should be made entirely of wood, and be provided with an elongated front in order to remove the lens far enough from the sensitive surface; this front may be made moveable, so that the camera may be used also for landscape and portraiture. In the lists of materials, &c., appended to this paper, two descriptions of camera are mentioned for a Government Photographer. The mahogany camera would be most generally serviceable, and that with an accordion body would be more convenient for expeditionary purposes.

The three points essential in a camera, are—

1st. That it keeps out the light perfectly.

2nd. That it is firm and steady.

3rd. That the focussing glass and dark slide are so carefully adjusted that when the former is replaced by the latter, the sensitive surface may occupy precisely the same position with reference to the lens that the roughened surface of the focussing glass had.

A failure in the 1st point will give *foggy* pictures, or pictures with dark spots recurring in the same place. A failure in the 2nd point will be fatal to the *sharpness* of the negative when there is any wind, as the camera will move, and a number of images will be formed instead of one. If the 3rd point be not attended to the pictures must always be out of focus, however carefully they may have been focussed on the greyed glass.

The steadiest form of tripod-stand for a large camera is that in which there are three long screws which pass through the tops of the legs and through the metal triangular frame on which the camera rests. These screws can be tightened up and the stand made perfectly firm.

For a small camera the more usual form of tripod, in which the elasticity of the wood of which the legs are made serves to keep the two portions of each leg firmly pressed against the triangular top, is sufficiently steady, but legs which have a joint in the middle of their length are never steady.

It is of importance that the focussing glass should be of glass specially prepared for the purpose and very finely greyed, or it will be difficult to focus correctly.

When working with paper, a different form of dark slide for the camera is required from that suited for collodion on glass.

As regards the *size* of camera, it must depend very much on the expense which it is intended to incur; but it should be borne in mind that the difficulties of the manipulation and the weight to be carried increase rapidly with the size of the picture, and also that the quantity of collodion and other chemicals necessary must vary as the areas of the glass plates used.

Plates 10 inches by 12 inches, or 9 inches by 11 inches, are those usually employed by the photographers of the Corps, and for Government purposes the size ought not, in my opinion, to be diminished; but for an amateur I should recommend a camera that will take pictures of what is called the whole plate size, viz., $8\frac{1}{2}$ inches by $6\frac{1}{2}$ inches, or even as small as 6 inches by 5 inches: and there should be a spare frame to fit in the dark slide to take plates $4\frac{1}{4}$ inches by $3\frac{1}{4}$ inches for portraits. Cameras are sometimes made *square*, so as to allow of the plate being used with its greater dimension either horizontal or vertical. This is useful in architectural subjects occasionally, but the same object may be obtained with greater portability (though at a sacrifice of convenience) by making the camera so that it can be fixed on the stand, either on its *bottom* or on its *side*.

The stereoscopic camera is preferred by some, and it has its advantages; but the larger single picture which may be obtained on a plate of the same area is in most respects more satisfactory than the two small ones, and when viewed with *one eye*

gives the same effects of solidity and distance so well that it appears to me very much to be preferred.

THE BATH for containing the nitrate of silver solution for sensitizing plates is best made of gutta percha, enclosed in a wooden case with a top which screws on. The inside of the bath should be coated with shell-lac varnish, by dissolving shell-lac in methylated alcohol in the proportion of about 1 oz. of shell-lac to 6 oz. of alcohol, and pouring it into the bath and letting it flow all over the interior, when the superfluous liquid may be poured off, and the bath left to drain mouth downwards, until the lac has hardened, which will generally take place in about 12 hours. This precaution is necessary owing to the impurities which are frequently found in commercial gutta percha, and which decompose the nitrate of silver. The dipper should be of glass.

Glass baths in wooden cases are very good, but they are expensive, heavy, and very liable to fracture. The bath should be at least 1 inch deeper than the length of the plate to be immersed in it, to avoid spilling and to insure the plate being covered with the solution.

THE LENSES are the most important part of the apparatus; defects in the camera and even in the chemicals may be remedied more or less perfectly, but a bad lens is fatal; therefore I should not recommend economy in this particular.

For landscape photography the ordinary view-lens obtained from a good maker is as satisfactory as any; but in architectural subjects the distortion which is unavoidable in this form of lens is very annoying, especially in the vertical lines of buildings, which are invariably bent into curves.

For such subjects the new form of lens known as the "orthoscopic" or "caloscopic" lens is very useful, as it corrects the distortion above alluded to; it gives also a *flatter field* than the ordinary view-lens, that is, if the object to be copied be nearly in one plane, such as a drawing, the whole of it will be brought clearly into focus from the centre to the edge, which will be found to be impossible with the ordinary single view-lens, the image formed by the latter being on a curved surface while the surface on which it is received is flat.

In taking a view, however, in which there are objects at various distances from the camera, the orthoscopic lens is inferior to the ordinary view-lens, as it has not the same *depth* of focus, *i.e.* objects in the foreground and in the middle distance cannot both be sharply focussed, while the extreme distance is almost lost. By using a small stop or diaphragm with the ordinary view-lens, objects in the foreground and distance may both be photographed at the same time with considerable success.

The aplanatic lens, patented by Mr. Grubb, is said to combine in some measure the good qualities of both the before-mentioned lenses; the one which I have used, however, does not give straighter lines than the ordinary view-lens; but it is exceedingly convenient in some cases from having a very short focus and taking in a larger angular extent of subject than either of the other lenses. On the whole, for taking views, I should recommend both a Grubb lens and a caloscopic or orthoscopic lens for government purposes, and the former only, or even a good ordinary view lens, for an amateur. For taking portraits there should always be a separate lens.

In portrait lenses the chance of getting an inferior article is very great if cheap makers be resorted to. Ross's are said to be the best. Grubb's are also very good. Those made by Horne and Thornthwait are also good and not quite so expensive. Doubtless many other makers produce equally good articles; but good lenses have a certain market value, and below that price the lenses must be inferior.

As the diameters of portrait lenses increase, so also do the difficulties of manufacture and the price, hence small portrait lenses to cover plates of from 4 inches by 3 inches to $6\frac{1}{2}$ inches by $4\frac{3}{4}$ inches, and costing from £5 to £10, are to be preferred

for amateurs. The French portrait lenses are cheaper than those of English manufacture, and if carefully selected are often very good.

Lenses are sold which by changing the positions of the glasses may be made to answer both for landscapes and for taking portraits, either of single figures or of groups. When such lenses are really good they have undoubted advantages on the score of portability and cheapness; but the unscrewing and refitting the glasses is inconvenient, and there is always a risk of dropping the glasses and injuring them, moreover the action of these lenses is seldom perfect. The best are said to be those made by Jamin of Paris.

The Dark Room or Tent.—An operating chamber from which white light is excluded may generally be fitted up in any building with very little labour or expense. The conditions required are that it should be free from dust and draughts of air, that all white light should be excluded, but enough yellow or orange light admitted to work by. The proper amount of yellow light may be obtained by means of yellow glass, or yellow calico, or a candle. The operating room should have a waste sink and a good supply of water, and for the latter a tap is very convenient. An even temperature of about 60° with a moderately dry atmosphere is best.

For a portable tent a simple frame-work of light wood, about 6½ feet high, supporting a light board for a table, about 15 inches by 30 inches, at 4 feet from the ground, with a covering thrown over all consisting of two thicknesses of yellow calico and one of black calico, is very convenient. An opening 1 foot square for a window should be left in the black calico, and an extra thickness of yellow calico may be substituted for it if the light be too strong. American drill-dyed orange is better than yellow calico if it can be procured. A very simple form of tent is described in Hardwich's Photographic Chemistry, page 261; but I should recommend that the covering should be allowed to fall down to the ground, and that it should have a double lap in front so as to allow the operator to get in without being tied into a bag. The form of tent-frame used at Chatham, designed by Captain Fowke, R.E., is quite portable, the long pieces, which form the sides, being jointed, and the table secured to them by brass thumb-screws; the top bars are halved together and kept in place by spikes on the side pieces.

Packing and Transport.—In taking photographs in the vicinity of Chatham we have found it convenient to pack all the materials required for a day's work in one box about 2 feet 9 inches by 1 foot 5 inches, by 10 inches deep, which is carried by two men by means of two poles; or light wheels may be fitted to the box, and it can be drawn by one man where there are roads. As this box holds all the materials for a day's work with plates 10 inches by 12 inches, a much smaller box will suffice for an amateur using a camera for pictures 8½ inches by 6½ inches. On service, or in most foreign countries, it will be found more convenient to divide the apparatus between two boxes, which will be more manageable, and may be slung on either side of a pack-saddle. The chemicals should be packed in one box with compartments, and the camera, plates, &c., in the other. The tent would form a third package, and might be secured conveniently on the top of a pack-saddle between the boxes. In travelling any distance it is best to pour off the bath and solution into a large bottle kept for the purpose, which should be impervious to light. A square gutta percha bottle, varnished inside with shell-lac, will be found very convenient for the purpose. For a short distance the bath may be carried by hand in its trough with the lid screwed down.

Sun-Printing.—Flat porcelain dishes are best for preparing sensitive paper for printing, and for toning the prints with chloride of gold; and pressure frames with *spring* backs are preferable to those where the pressure is applied by means of screws, as the irregular pressure of the latter frequently breaks the negatives. American clips are very useful for hanging up the paper to dry. In albumenizing

large quantities of paper for printing, it is much quicker to brush the albumen solution on with broad flat brushes of hogs' hair (such as those used by house painters) than to float the paper on the solution in the ordinary way. The solution is brushed on evenly in one direction first, and the sheets hung up to dry; when dry a second coating is given, the brush being used in a direction at right angles to that at first adopted, and the paper is again hung up to dry. The operation requires care to avoid streaks or bubbles; but after a little practice it becomes very easy. It is best performed on a board rather smaller than the sheet to be albumenized; this prevents the brush from becoming contaminated with dirt, as it touches nothing but the surface of the paper. Amateurs are however recommended to purchase albumenized paper from respectable dealers.

A few gutta percha trays are very useful for washing prints, for fixing them, for catching the waste solutions when developing in a tent, and for washing collodion plates when preparing them for any of the dry processes.

The paper best suited for photographic printing, especially when the pictures are small, is that known as *negative* paper, and "Canson's" is generally considered the finest. The thicker sorts of paper, called positive paper, are sometimes useful for large subjects.

The glass recommended generally for collodion negatives is patent plate, which is very expensive. The best 16oz. sheet glass answers the purpose sufficiently well and is much cheaper. Such glass is however sometimes difficult to clean, and occasionally it is not quite flat, which makes it unsuitable for the purpose of photography.

The pneumatic plate holder is indispensable for plates larger than $8\frac{1}{2}$ inches by $6\frac{1}{2}$ inches, and it is very convenient for these or even smaller plates. The globe plate holder is a convenient form for small plates.

The Chemicals required for photographic purposes should be exceedingly pure, or the results will be generally unsatisfactory. It is recommended that they be obtained from makers of reputation, who devote their attention to this branch especially. We have dealt with Messrs. Thomas, 10, Pall Mall; Hopkin and Williams, 5, New Cavendish Street, Portland Place; or Burfield and Rouch, 180, Strand, London.

Two lists are appended to this Paper, the one giving the materials required for a year's supply for a photographer constantly employed on Government work; the other for a small equipment for an amateur working with plates 7 inches by 6 inches for views, and $4\frac{1}{4}$ inches by $3\frac{1}{4}$ inches for portraits.

For foreign stations more than usual care must be used in selecting the collodion, as it is a very unstable compound, and if not perfectly pure, and prepared in the best manner, it rapidly becomes unfit for use. Mr. Hardwich's collodion, now manufactured by Messrs. Burfield and Rouch, bears a very high character; so also do those manufactured by Mr. Thomas, Pall Mall, London, and by Mr. Keen, of Leamington. The last named is specially adapted for the dry processes, and may be obtained from any respectable dealer. At the Ordnance Survey Office, Southampton, pyroxyline has been obtained from Mons. Cappe, 4, Quai de Billet, Paris, and we have used the same here for a considerable time. At first it gave admirable results, but it has deteriorated by keeping, and latterly we have found it uncertain in its action. If pyroxyline be purchased, and made into collodion as required, the ether used must be carefully preserved from the effects of light and heat, or the collodion will rapidly assume a dark colour on being iodized, and become insensitive and useless.

Upon the whole I should not recommend amateurs to attempt the manufacture of their own collodion, unless they are expert chemists. The substance is so very

easily altered in its properties, that failures are almost certain to occur frequently, and it will be better and cheaper eventually to purchase the collodion from good makers. It will be well, however, to have two iodizing solutions—one iodide of cadmium, the other iodide of potassium; these two iodizers are now sold with nearly all good collodions, and may be varied according to circumstances. The cadmium iodizer is very valuable in hot climates, as collodion there rapidly acquires the property of liberating iodine from iodide of potassium, when it gives weak pictures and requires long exposure. It will be best also to get collodion sent out in small quantities at a time; there will thus be less risk of the whole stock turning bad.

I have made no mention of the positive collodion process, because the negative process is so much to be preferred, that it is not worth while for an officer who has other occupations to waste his time upon it; and as the pictures cannot be multiplied, and are on such a heavy and fragile material as glass, they are useless for military purposes.

Some general directions, not found in most books on the subject, with reference to the process of taking negatives on glass, and printing positives on paper, may be useful in conclusion; but for full details of the process, with explanations of the chemical theory, and directions for overcoming all sorts of photographic difficulties, the reader is referred to the 5th edition of "Hardwich's Photographic Chemistry."

General Directions for Taking Negatives.—After having tried nearly all the various methods recommended for cleaning photographic glasses, we have not found any more convenient detergent than tripoli powder mixed with enough diluted alcohol (1 alcohol to 6 water) to bring it to the consistency of cream. In applying this a small quantity is dropped on the plate, which is laid on a pad of blotting paper, and with a tuft of cotton wool the tripoli is well rubbed over the surface, and cleaned off with another tuft; the plate is then turned over, and the other side treated in like manner, and the edges carefully wiped; it is then examined to see if there be any scratch or flaws on either side, and the best side is selected for the collodion, the pneumatic holder is fixed to the other side, and the surface is polished with an old silk handkerchief, or piece of wash leather, the latter being rather preferable. A little methylated alcohol is often sufficient to remove a slight stain on the glass.

The bath should always be kept covered to preserve it from dust and light, a brown paper cap which will drop on loosely is most convenient in the operating room.

In very hot climates chemical changes proceed so rapidly that half a minute or less in the bath may be sufficient, although in cold weather from 2 to 5 minutes is generally necessary.

The plate should be well drained before putting it into the camera slide, and if this is done on the dipper over the bath a good deal of solution will be saved. A strip of clean blotting paper laid on the back of the plate near its lower edge, after it is placed in the slide, is a useful precaution, as it saves the slide from the corroding action of the waste solution which would otherwise run down into the groove at the bottom, and which also is a fruitful source of spots on the picture from the slide being shut down too forcibly and splashing up some of this liquid on to the plate.

The sooner the plate is exposed and developed the better, especially in hot weather; but in cool damp weather, if the collodion gives a good thick creamy film, it may sometimes be kept for half an hour, or even three-quarters of an hour; and when the necessity of a very long exposure, as in photographing interiors, obliges such a course, it may be useful to re-dip the plate in the bath before developing: this practice is not, however, to be recommended, as there is great danger of carrying some organic impurity into the bath, and so putting it out of order.

In developing an under exposed picture in which the details of the shadows appear very slowly, the development should be carried on as far as possible before adding nitrate of silver to the solution. If the picture be over exposed, on the other hand, it is best to fix it as soon as the details of the shadows appear, and after well washing it, it may be intensified if necessary with pyrogallic acid and nitrate of silver.

When hyposulphite of soda is used for fixing (which I should generally advise in preference to cyanide of potassium), it is best to leave the plate for a while in a dish of water before intensifying it, as the least trace of hyposulphite of soda remaining on the film would cause a stain.

In cases when a sufficient supply of water for washing the picture after fixing is not procurable, cyanide of potassium may be preferable to hyposulphite of soda, as it is more easily removed; but it must be used very carefully, or the delicate half-tones of the picture will be injured.

A very excellent and durable varnish is made by dissolving white lac in alcohol, but it requires the aid of artificial heat to dry it rapidly, or it will have a dull surface.

Good varnishes are sold composed chiefly of gum benzoin or amber dissolved in chloroform, which may be used without artificial heat and are therefore more convenient; they are, however, more expensive.

In photographing landscapes or architectural subjects, a view-meter is exceedingly useful; it is a small hollow truncated pyramid of tin, constructed so that when applied to the eye, the field of vision is limited to exactly what will be depicted upon the sensitive surface by the lens to which it corresponds. The best point of view may thus be selected without moving the camera from place to place. Full consideration should invariably be given to this important particular, as the value of the finished photograph, as a picture, will mainly depend upon the taste and judgment displayed in selecting the point of view.

A moveable front to the camera is frequently of great use in regulating the amount of foreground in the picture without disturbing the horizontal position of the camera, which should always be carefully preserved, or the subject will be distorted into the shape of a pyramid, the vertical lines converging upwards or downwards according to the direction in which the camera is inclined.

In focussing, the principal objects should be most sharply defined, and in general a want of clear definition in the foreground will be more disagreeable than if the distance be slightly out of focus.

In judging the necessary time of exposure, which can only be done by practice, it should be remembered that the total amount of light which is thrown on the sensitive surface through the lens mainly influences the results. For instance, a large building covered with ivy, which occupies nearly the whole of the picture, would require a considerably longer exposure than a corner of a wall of the same building occurring in a portion of a well lit landscape, although the camera were at the same distance from the building in both cases. On the same principle, the nearer the object to be copied is to the camera the longer will be the necessary exposure to produce a good picture.

In copying drawings, &c., with the elongated front, it is essential that the planes of the picture to be copied, and of the sensitive surface, be exactly parallel, otherwise distortion of the image will result. A small stop is necessary in copying drawings with the ordinary view-lens to overcome, as far as possible, the curving of straight lines into a barrel shape, which is the great defect of that form of lens. The curvature of the image (*i. e.* its being formed on a curved surface instead of a plane one, as before mentioned) renders it impossible to focus the whole picture with equal

sharpness, it is best therefore to focus on an annular ring midway between the centre and outside of the picture; by this means the whole picture is nearly in focus. When great accuracy is required only a small portion of the field of view should be used, say 7 inches square for a lens used to cover a 10″ x 12″ plate. With a good lens the distortion may thus be so far reduced as to become inappreciable. When the drawing to be copied is at all yellow or soiled it is generally necessary to intensify the negative by means of bichloride of mercury to obtain good results.

The mode of doing so is as follows :—The negative is rather under exposed and is developed and fixed as usual, but not intensified with nitrate of silver; it is then immersed in a saturated solution of bichloride of mercury till it is thoroughly whitened; it is then washed and flooded with a solution of 10 parts of water to 1 part of hydrosulphate of ammonia, which rapidly forms a sulphuret of silver and mercury of great density. The picture is then washed and varnished as usual: should the hydrosulphate of ammonia be too weak, sufficient density will not be attained.

To clean the glasses after they have been used in this way it is necessary to soak them in a strong solution of iodine and iodide of potassium before applying the tripoli powder.

In portraiture, the grouping of the figures, the dress, and the background all require careful attention. A dark background gives generally the most pleasing effect, and the figure stands out better from the background when the latter is slightly out of focus. It is generally necessary, in photographing a single sitting figure, to point the axis of the lens somewhat downwards, so as to bring the focussing screen nearly parallel to the general direction of the figure.

Groups of figures may be taken successfully in a good light, with a single lens of short focus, using the largest aperture. A good portrait lens is however generally better for the purpose, as the necessary time of exposure is shorter. In using a portrait lens in such cases, the group should be arranged in a curved form, the figures on the outside being advanced towards the camera; and if two rows of figures are necessary, those in the front row should be children or sitting figures, and the camera should then be pointed downwards, so as to bring all the faces into focus. Taste and judgment will be required to avoid stiffness in the grouping.

Animals must generally be photographed in the sunlight, when, with a good portrait lens, and under favourable circumstances, from half a second to one second will be sufficient exposure; but the gradations of half-tone are seldom so well rendered as when the object is placed in a more subdued and equally diffused light.

As a general rule, the position to be preferred for the camera, with reference to the sun, is when the sun is behind the camera and shines upon the scene to be depicted; but cases frequently occur when it is necessary to reverse this position. When this happens, or when the reflection of the sun from water, or light-coloured ground, is thrown upwards into the lens, it becomes necessary to shade the lens from such direct or reflected rays of the sun, and this may generally be effected by means of a focussing cloth or other dark material held in the necessary position.

It is also a very excellent rule to throw a focussing cloth over the body of the camera before raising the slide which exposes the sensitive surface; this prevents any rays of light reaching the plate through the slit in which the slide works, or through any other minute chinks which may exist in the camera.

Sergeant Church, R.E., when employed as a photographer in the very hot climate of Honduras, found it a useful precaution to put a wet cloth over the "chassis" (dark slide) when carrying it from the operating tent to the camera, and to spread this cloth over the camera during the time the plate was being exposed; this kept down the temperature and prevented the very rapid evaporation which would otherwise have dried up the surface of the plate before he could have developed it. He also found it a great assistance when water was near at hand to pour a few bucket-

fuls on the ground before pitching his operating tent; this diminished the chances of dust spoiling the picture, and by producing an artificially humid atmosphere, the condensed moisture from the breath could be observed on the plate, so as to ascertain if it were clean, which cannot be done when the air is very hot and dry.

For preparing the nitrate of silver baths, and most of the solutions used in photography, distilled water is necessary; but for the developing solutions good filtered rain-water or river-water will answer sufficiently well. If the water be brackish, or contains any chlorides in solution (as is the case in most hard waters), it will cause a precipitate of chloride of silver on the plate and interfere with the development. When it is difficult to procure better water it will answer if nitrate of silver solution be dropped in until no further milkiness results; but this is of course an expensive expedient.

For washing positive prints, ordinary hard water answers well, though river water, if procurable in sufficient quantity, is generally considered preferable.

Small defects in the skies or in unimportant parts of negatives may be painted out easily with indian-ink and a fine brush on the collodion surface before the negative is varnished; but after varnishing, such touching out becomes more difficult.

Defective skies may sometimes be stopped out on the negative by taking a print and cutting it out carefully along the line of the horizon; the sky portion is then exposed to the sun and fully darkened and gummed to the back of the negative, but it is necessary to paint out the edge of the horizon on the collodion side to prevent any light getting round the edges of the paper. In general, however, it is best to shade out defective skies by a piece of pasteboard outside the glass of the printing frame, arched up from it so as to avoid a hard line; and whenever shading out is resorted to, the printing must be carried on in the shade, not in direct sunlight, or a hard line of demarcation between the shaded and unshaded portions will result.

In conclusion, I would recommend any one who wishes to excel in photography to study the chemical theory of the subject. Hardwich's Photographic Chemistry is generally accepted as the best work which has yet been printed: in it will be found every sort of information which the beginner or the more experienced photographer can desire.

The details of the best process for obtaining positive proofs on paper have, however, altered slightly since the last edition of that work was published. I have therefore introduced them in the appendix to this paper; the process there described was first published in No. 8 of the 1st Volume of the Photographic News, October 29, 1858, by a person signing himself "θ."

This process has been practised at this establishment ever since, and has been found so immeasurably superior to the old method of toning and fixing in the same bath, that no one who wishes to obtain pleasant tones, clear whites, and prints which may reasonably be expected to be permanent, should hesitate to incur the very little extra trouble which "Theta's" process involves.

Appendix.

Solutions for Preparing Paper for Printing.

Albumen.

White of egg	1 ounce.
Chloride of Ammonium	20 grains.
Distilled water	1 ounce.

When paper is floated on this solution it should remain in contact not more than one minute and a half if thin, or two minutes if the paper is thick. In warm bright weather the chloride may be reduced from 10 to 7 grains per ounce, and the silver in the sensitizing bath must be reduced in proportion (say 45 grains). If a very

glossy surface be desired for small portraits, &c., more albumen should be used in proportion to the water, say $1\frac{1}{2}$ oz. of albumen to $\frac{1}{2}$ oz. water.

Sensitizing Bath.

Nitrate of silver	60 grains.
Water (distilled)	1 ounce.

The paper to remain in contact with this solution five minutes.

In using albumenized paper prepared with 10 grains of chloride to the ounce of solution and a sensitizing bath of 50 grains of nitrate to the ounce, floating 10 sheets of paper 10 in. by 12 in. (on a 10 ounce bath) reduces the strength of the solution from 50 to 40 grains per ounce, and uses one ounce of the solution.

Therefore, after sensitizing ten large sheets, 10 in. by 12 in., or 30 small sheets, 6 in. by 8 in., add 1 ounce of solution, of 100 grains to the ounce, to the bath to keep it up to the full strength. If the strength of the bath be allowed to fall too low the prints will be weak and mottled.

SOLUTIONS FOR TONING AND FIXING POSITIVE PRINTS BY "THETA'S" PROCESS.

1st Bath.	Common water	30 ounces.
	Ammonia	1 drachm.
	Solution A.	
2nd Bath. (Toning.)	Carbonate of Soda	125 grains.
	Common water	30 ounces.
	Solution B.	
	Chloride of gold	5 grains.
	Distilled water	30 ounces.
	Fixing Solution.	
3rd Bath. (Fixing.)	Hyposulphite of soda	6 ounces.
	Common water	30 ounces

Solutions A and B ought to be mixed in equal proportions immediately before being used, and only in sufficient quantity to tone the number of prints required. One grain of gold will tone about four 10 in. by 12 in. prints by this process. The proofs must be printed deeply, and the whole of the silver washed out in two waters before immersion in the ammonia bath, in which they must remain *five minutes*. They are then to be washed in one water and removed to the *toning bath*, and left there till *very purple;* then washed again and placed in the fixing bath for about *fifteen minutes*. They are then washed as usual for twelve hours in running water and hung up to dry.

ACCOUNT OF THE WAXED PAPER PROCESS AS PRACTISED SUCCESSFULLY IN BOMBAY, BY MR. H. STANLEY CRAWFORD.

PUBLISHED IN NO. 58 OF THE 2ND VOL. OF THE PHOTOGRAPHIC NEWS.

* * * * "To wax paper, I shall give no particular formula, so many excellent modes having already been given, nearly all of which answer equally well here as in a cooler clime. For my own part I prefer purchasing ready waxed paper, thereby saving myself the inconvenience of a troublesome operation. In purchasing waxed paper, however, it should be carefully examined sheet by sheet; those free from conspicuous flaws should be selected, and while having the appearance of being thoroughly saturated with wax and quite transparent, they should present no shiny patches on the surface, but a uniform dull smoothness: should shining patches appear

on paper in other respects good, the objection may be got rid of by carefully ironing the sheet between clean folds of bibulous paper.

"Waxed paper, whether in its plain state or iodized, should always be kept in a portfolio, and in as cool a situation as practicable.

"The iodizing solution I have found to answer best, is made as follows:—

"No. 1. In 20 ounces of distilled water dissolve 480 grains of iodide of potassium.

"No. 2. In 10 ounces of distilled water dissolve 96 grains of bromide of potassium, and then add 24 grains of chloride of potassium.

"No. 3. In 10 ounces of distilled water dissolve 10 grains of cyanide of potassium.

"No. 4. In 4 ounces of distilled water dissolve 5 grains of iodine.

"Mix solutions Nos. 1 and 4 together, agitate well, and then add No. 2 solution to it and agitate well; finally throw in solution No. 3, and agitate well. This solution should be kept in a well-stoppered bottle covered from light, and will be of service till entirely expended.

"When required for use, this liquid should be filtered through white clean bibulous paper into a pan of good depth, and as many sheets of paper as are required may be immersed one by one in it; care being taken that no air bubbles adhere to the paper, either above or below, and that the liquid quite covers the whole mass of paper.

"The paper should now be allowed to soak in this solution from 6 to 10 hours, after which it may be taken out sheet by sheet, and hung up in a cool place (not exposed to much light) to dry; when dry it should be carefully wrapped in clean paper, and placed in a portfolio till wanted, and, with ordinary precautions, may in this state be preserved good for months.

"The exciting solution is made thus:—In 24 ounces of distilled water dissolve 2 ounces of crystallized nitrate of silver; when dissolved, add glacial acetic acid 2½ ounces, and finally add 5½ ounces of alcohol.

"Filter before use into a pan larger somewhat than the paper to be excited.

"Into this solution immerse one sheet of the iodized paper (taking great care that no bubbles adhere) and allow it to soak for about 5 minutes, when it should be taken out, and if to be kept for several days, placed in a similar pan containing pure distilled water, rinsed in it for a minute or two, and then dried off between folds of clean bibulous paper, where it should be retained ready for use in the camera. As many sheets as are needed may thus be prepared one after the other, and when finished should be kept in a portfolio in a cool place, and most cautiously excluded from light.

"To give any accurate time for the exposure necessary in the camera is almost an impossibility, but with a 3-in. view-lens, ½-in. opening, and our ordinary Indian light, five to six minutes would be about the time required by this paper for buildings, but for foliage or dark masses of architecture in shade, nine to twelve minutes would probably be better.

"It may not be out of place here to impress upon the mind of the novice the absolute necessity of the most strict caution not to allow the least ray of daylight to get at the sensitive paper when not under exposure through the lens to a view. Camera slides, no matter how carefully made, cannot thoroughly exclude our bright sunlight, and the only plan to ensure certainty is to wrap several folds of yellow cloth round the slides when not in use. Too much care cannot be bestowed upon these precautions.

"Paper made sensitive as above described may be kept, with the precautions advised, at least ten days with perfect confidence. I have worked with such paper 16 or 17 days after excitation, and found no appreciable diminution of effect, even in the time of exposure. It may also be kept several days after exposure in the camera

before being developed. At the same time it is always advisable to use the paper as soon after excitation as possible, as involving less chances of failure in excluding mishaps which might intervene by the lapse of time. The same remark applies to the development, which in particular should, if practicable, be done within 24 hours after the exposure in the camera.

"The developing solution is made by filling a bottle quite full with hot distilled water, and throwing into it as much gallic acid as the water will dissolve; when it will dissolve no more the solution should be allowed to cool and settle, then the clear liquid may be poured into a clean pan, say to the depth of a $\frac{1}{4}$ of an inch. Into this the impressioned sheet is immersed and allowed to remain for five or ten minutes. The picture rarely developes rapidly under this solution, there being so little free nitrate of silver left on the paper; it is necessary, therefore, to assist the development by throwing into it an ounce of the water in which the sensitive sheets were washed (which should be preserved in a bottle for this purpose); the picture will now rapidly develope, and from this moment the process requires very careful attention:—in the first place to check it at the point when all the details of the picture are properly out; and in the next, if the developing liquid shew symptoms of browning (decomposition), which in this climate will speedily occur in gallic acid to which free nitrate of silver has been added, to replace it immediately with fresh; a neglect of this precaution may perhaps destroy what would otherwise have proved a good picture.

"The time that the process of development occupies varies so much that none in particular can be stated. However, a picture is seldom out in less than a quarter of an hour, and it may be 12 or 20 hours, if the exposure in the camera was too short a time; in the latter case particular care must be taken to renew the gallic acid solution, should it shew symptoms of becoming brown.

"A picture should be allowed to go on developing so long as the whites or half-tones do not suffer, that is darken. When all the details appear distinctly visible, the sheet of paper should be held up between the eyes and a light; if the blacks in this position present a density impenetrable to light, the whites a clear transparency, and the half-tones a relative value, the operation should be stopped, the picture put into a pan of clean water and brushed on both sides with a soft broad camel's hair brush to remove any deposit that may have settled upon it; if allowed to remain thus for about half an hour, nearly all the acid will be washed out; it should then be passed through a fresh pan of water, and afterwards to remove the iodide, placed in a bath of cyanide of potassium, made as follows:—

Cyanide of potassium	80 grains.
Water	16 ounces.

Filter for use.

"This bath is preferable to one of hyposulphite of soda, inasmuch as it acts more quickly, is less bulky, and is safe in operation, for nothing can be more injurious in working than hyposulphite, the least contact of which is destructive to the exciting and iodizing baths.

"The cyanide bath is very energetic, and consequently the picture requires much attention when in it; for if left beyond the time sufficient to dispel the yellow iodide, it will, in continuing its action, reduce also the blacks—indeed, it would, if left for any lengthened time, entirely obliterate the picture.

"If a hyposulphite bath is preferred, the following will be found to answer well:—

Hyposulphite of soda	3 ounces.
Water	20 ounces.

Filter.

"When the iodide has thoroughly disappeared, the picture should be washed for an hour in several changes of water (say four or five times) and in a good supply of water each time: it should afterwards be hung up to dry.

"When thoroughly dry, expose to the sunshine for a few minutes, and finally iron with a moderately heated iron; this operation renews the transparency of the paper, which, in its continued and repeated washing, is in general somewhat impaired.

"In conclusion, I have only to recapitulate and throw out a few further precautions. Adopt the utmost cleanliness in every stage of the operation. Use no chemicals but what are guaranteed as the best. In exciting, use in the dark room no more light than is sufficient to enable work to be done with comfort. Use fresh clean bibulous paper for blotting off the paper after exciting. Filtered or otherwise, let all the solutions be perfectly clear and limpid. Use the greatest care in preserving the excited paper from the least ray of light when not under exposure in the camera, and so till the picture is developed. Never use the gallic acid bath after it has browned at all; after fixation in the cyanide bath, wash thoroughly in water to remove every trace of that solution. The paper, in every stage—in its plain, iodised, excited, impressed, and completed state—should always be wrapt in paper and laid flat in a portfolio, kept in a cool place. In this climate, every camera for out-door work should have a thick yellow quilted cover, which both serves as a protector to the wood, and excludes white light which might gain admission by any barely perceptible flaw, and also assists materially in maintaining a cool atmosphere about the paper. The lens must of course be wiped occasionally;* perfect knowledge of the proper use of the various sized diaphragms can only be acquired by experience and practice, but, as a general rule, the smallest sizes, compatible with the amount of light available, should be used.

Account of a Mode of Waxing Paper.
Extracted from the Photographic News, Vol. II.

"A dish of block tin, without joints in the bottom, and one inch deep, is made to fit into another and larger vessel, also of tin, containing boiling water, which must be kept at the boiling point by any convenient heater. A cake or two of white wax is put into the waxing dish, and when it is melted, the sheet of paper is floated thereon. When the paper is saturated with wax, take it up and drain off as much as possible of the superfluous wax. Do the same with any number of papers. Then with a clean box iron, † iron them one at a time between from four to six thicknesses of blotting paper, until the blotting paper is saturated with wax; then iron between fresh blotting paper, which may require to be repeated. The second and third blotting papers of the first batch will do the first and second ironing of the second batch. Proceed thus until all are ironed, and appear (when held between the eye and the light) free from any opaque or shining spots, and perfectly clear and transparent.

"Another method of waxing paper is to place the paper on two or three folds of blotting paper; then as you pass the iron over the back of the paper with one hand, follow it closely with a piece of wax held in the other—the excess of wax being ironed out as before. I do not recommend this mode of waxing papers previous to iodising, but it answers very well when one or two calotype negatives have to be waxed, and must do when the photographer is unprovided with a tray."

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* This is best done with chamois leather—it is less liable to scratch the glass than silk.

† English photographers lay great stress upon the iron not being used too hot, a very hot iron spoiling the paper.

LIST OF ARTICLES NECESSARY FOR A GOVERNMENT PHOTOGRAPHER (COLUMNS A.); OR FOR AN AMATEUR PHOTOGRAPHER (COLUMNS B.)

Description of Articles.	Quantity A.	Quantity B.	Rate.	Amount A.	Amount B.
			s. d.	£ s. d.	£ s. d.
Best extra white sheet glass—11 in. × 9 in.	12 doz.	...	1 2 per foot	5 14 6	...
6 in. × 8 in.	6 doz.	...	51 0 per gross	1 5 6	...
6 in. × 7 in.	...	6 doz.	42 0 ,,	...	1 1 0
$4\frac{1}{4}$ in. × $3\frac{1}{4}$ in.	...	6 doz.	12 6 ,,	...	0 6 3
Bath, gutta percha in wooden case with glass dipper	2 (10″ × 12″)	1 (7″ × 8″)	17 6	1 15 0	0 10 0
Scales and weights, (glass pans)	1	1	5 9	0 5 9	0 5 9
Funnels, gutta percha, two (nested)	4	2	1 6 per pair	0 3 0	0 1 6
Ditto glass	2 large	2 small	...	0 2 0	0 1 0
Glass graduated measures (20 oz., 8 oz., 4 oz. and minim)	2 of each	...	6 1	0 12 2	...
Ditto ditto (4 oz., 1 oz., 1 dr.)	...	1 set	3 9	...	0 3 9
Gutta percha bottles for cyanide and developer	4 16-oz.	2 8-oz.	2 or 1s.	0 8 0	0 2 0
Pneumatic plate holders	4	2	3 6	0 14 0	0 3 6
Spare tops for ditto	4	2	1 0	0 4 0	0 1 6
Focussing cloths	2	1	2 6	0 5 0	0 2 6
Dishes for sensitising paper, porcelain	2	1	...	0 7 6	0 1 4
Ditto, for washing in, gutta percha (nested)	6	3	...	2 5 0	0 7 0
Still and refrigerator for water	2-gallon	½-gallon	...	1 2 0	0 14 0
Portable bucket for water	2	...	14 0	1 8 0	...
Pressure frames for printing with spring backs	4 (10″ × 12″)	1 (7″ × 8″)	...	2 8 0	0 7 6
Spare glasses for ditto	2	...	2 0	0 4 0	...
Ditto focussing glasses	2	1	...	0 3 6	0 1 6
Ditto glass dippers	2	1	...	0 1 4	0 0 9
Gutta percha square bottles for bath, &c.	2 (80 ozs.)	1 (30 ozs.)	...	0 13 0	0 3 0
Glaziers' diamond	1	1	...	0 17 6	...
Pins, tape, tacks, and American clips	an assortment	an assortment	...	0 4 0	0 2 0
Hammer and screw driver	1 of each	...	...	0 2 9	0 2 9
View meters	3	1	...	0 6 0	0 1 6
Dark tent	1	1	...	4 0 0	1 10 0
Boxes for holding plates for 11 in. × 9 in.	4 doz.	...	...	1 0 0	...
6 in. × 8 in.	2 doz.	...	...	0 7 0	...
6 in. × 7 in.	...	2 doz.	...	...	0 6 0
$4\frac{1}{4}$ in. × $3\frac{1}{4}$ in.	...	2 doz.	...	...	0 3 6
				£26 18 6	£6 19 7

List of Articles Necessary for a Gove nment Photographer (Columns A.);
or for an Amateur Photographer (Columns B.)—*Continued.*

Description of Articles.	Quantity A.	Quantity B.	Rate.	Amount A.	Amount B.
			s. d.	£ s. d.	£ s. d.
Brought over	... ...	... ...	... ...	26 18 6	6 19 7
Thermometers	2	1	3 0	0 6 0	0 3 0
Camera folding and expanding with moveable elongated front, in mahogany, brass bound, for 11-in. × 9-in. pictures Or ditto, with accordion body, for 11-in. × 9-in. do.	1	... ...	... ...	9 9 0	...
Ditto, expanding Spanish mahogany brass-bound for 6-in. × 7-in. do.	... ...	1	... ...	... ...	5 6 6
Spare camera back for 11-in. × 9-in. ditto	2 { for paper and for glass }	... ...	... ...	3 5 6	...
Ditto ditto for 6-in. × 7-in. ditto	... ...	1 *for paper*	... ...	... ...	1 2 0
Aplanatic lens (Grubb's) for 11-in. × 9-in. ditto	1	... ...	... ...	5 0 0	...
Caloscopic lens (Horne and Co's.) for 11-in. × 9-in. ditto	1	... ...	... ...	6 0 0	...
Aplanatic lens (Grubb's) for 6-in. × 7-in. ditto	... ...	1	... ..	... ...	3 10 0
Portrait lens (Grubb or Ross') for 3¼-in. × 4¼-in. ditto	... ...	1	... ...	... ...	5 0 0
Tripod stands	1	1	... ...	1 10 0	1 1 0
Boxes for a day's supply, fitted with compartments, lined with cork	2	... ...	... ...	2 0 0	...
Store box for apparatus	1	1	... ...	2 10 0	1 0 0
				56 19 0	24 2 1
Add for chemicals, &c.	... ...	... ...	... ...	45 0 0	11 1 5½
				101 19 0	35 3 6½
D. D. 15 per cent. for cash	... ...	... ...	... ..	15 0 0	5 5 10
Say nett	... ...	... ...	... ...	87 0 0	30 0 0

H. SCHAW, Captain, Royal Engineers.
14th May, 1860.

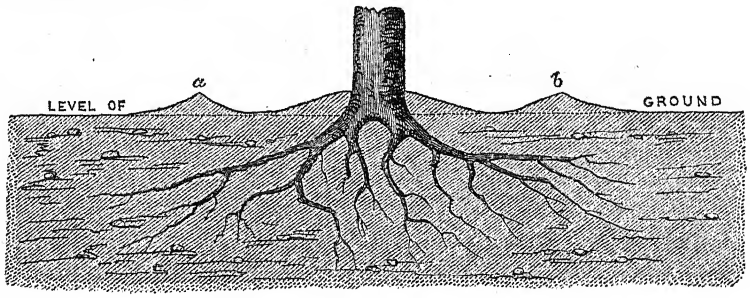
N.B.—The prices of the chemicals are taken from the price-list of Messrs. Burfield and Rouch, 180, Strand, London; those of the apparatus from the price-list of Messrs. Horne and Thornthwait, 121, Newgate Street, London; or of Messrs. Bland and Long, 153, Fleet Street, London; and those of the glass from the price-list of Mr. P. Palmer, 118, St. Martin's Lane, London. The prices vary slightly from time to time; but the above are a fair average.—H. S.

List of Chemicals Necessary for a Year's Supply for a Government Photographer (Columns A.); or for a Year's Supply for an Amateur Photographer (Columns B.)

Description of Article.	Quantity A.	Quantity B.	Rate.	Amount A.	Amount B.
			s. d.	£ s. d.	£ s. d.
"Hardwich's" or other good negative collodion	10 pints 4 at a time	2 pints ½-pint bottles	16 0	8 0 0	1 12 0
Canson's negative paper	6 quires	1 quire	3 0	0 18 0	0 3 0
Ditto ditto albumenized	6 ,,	1 ,,	10 0	3 0 0	0 10 0
Ditto ditto waxed	1 ,,	1 ,,	7 0	0 7 0	0 7 0
White blotting paper	10 ,,	2 ,,	1 0	0 10 0	0 2 0
Swedish filtering paper	6 ,,	1 ,,	1 3	0 7 6	0 1 3
Absolute alcohol	40 ozs.	6 ozs.	0 4	0 13 4	0 2 0
Methylated ditto	120 ozs.	30 ozs.	0 1	0 10 0	0 2 6
Sulphuric ether	40 ozs.	6 ozs.	0 4	0 13 4	0 2 0
Glacial acetic acid	120 ozs.	30 ozs.	0 4	2 0 0	0 10 0
Citric acid	16 ozs.	3 ozs.	0 4	0 5 4	0 1 0
Pyrogallic acid	8 ozs.	1½ ozs.	4 6	1 16 0	0 6 9
Gallic acid	10 ozs.	5 ozs.	1 0	0 10 0	0 5 0
Protosulphate of iron	2 lbs.	1 lb.	0 8	0 1 4	0 0 8
Nitrate of silver (pure re-crystallised)	4 lbs.	1 lb.	64 0	12 16 0	3 4 0
Liquor ammonia	12 ozs.	4 ozs.	0 2	0 2 0	0 0 8
Carbonate of soda	1 lb.	¼ lb.	1 6	0 1 6	0 0 4½
Iodide of potassium	4 ozs.	1½ ozs.	1 4	0 5 4	0 2 0
Bromide of potassium	4 drs.	2 drs.	1 6 per oz.	0 0 9	0 0 4½
Chloride of potassium	2 drs.	1 dr.	1 6 per oz.	0 0 4½	0 0 2¼
Iodide of cadmium	2 drs.	1 dr.	1 4 per oz.	0 0 4	0 0 2
Cyanide of potassium	2 lbs.	1 lb.	2 9 per lb.	0 5 6	0 2 9
Hyposulphite of soda	36 lbs.	10 lbs.	0 5	0 15 0	0 4 2
Chloride of gold	8 drs.	1 dr.	7 6	3 0 0	0 7 6
Chloride of ammonium	2 lbs.	½ lb.	1 9	0 3 6	0 0 10½
Iodine	2 drs.	1 dr.	1 6 per oz.	0 0 4½	0 0 2¼
Kaolin	2 lbs.	½ lb.	0 9	0 1 6	0 0 4½
Gum camphor	6 ozs.	2 ozs.	0 4	0 2 0	0 0 8
Gum arabic	1 lb.	4 ozs.	0 3 per oz.	0 4 0	0 1 0
Litmus paper	6 books.	2 books.	0 6	0 3 0	0 1 0
Varnish (chloroform)	80 ozs.	12 ozs.	0 10	3 6 8	0 10 0
Tripoli powder	2 lbs.	1 lb.	3 6	0 7 0	0 3 6
Cotton wool	6 lbs.	2 lbs.	2 0	0 12 0	0 4 0
Shellac brown	1 lb.	¼ lb.	1 4	0 1 4	0 0 4
Packing case and bottles	... ...	... ...	... ...	3 0 0	1 10 0
				45 0 0	11 1 5½

PLANTING TREES.—It may be observed that luxuriant trees, whether old or young, have the upper parts of the roots, where they divide from the stem, above the surface of the ground; and that, on the contrary, those which have a portion of their bark below the ground, generally exhibit an imperfect growth.

While a tree will live though its inside be hollow, it will die if a knife be passed round its trunk, so as to girdle the bark; the vital part not being in its centre, but just under the bark, where nature adds, season after season, to its growth. Hence, if the stem be so situated as that the bark be rotted, the same effect will be produced as if girdled by a knife.



The section suggests the manner in which a tree should be planted; and when on hard ground, it is desirable to surround it by a little bank, as shown at *a b*, to catch the rain in such a way, as that it may soak to the fibres of the roots, leaving the stem dry.

Another cause of failure in transplanting trees is owing to the roots being too much cut away, instead of digging them up with care, and then placing them in the ground in a similar manner, copying nature as nearly as possible.—S. B. H.

POINT-BLANK.—In the *British Service*, "a piece of ordnance is said to be point-blank for an object when the axis of the gun and the object are in the same plane; which may be either parallel or inclined to the horizon: hence the point-blank range of a piece of ordnance, or its range at no elevation, is the distance from the muzzle of the gun to the first grăze, measured upon a plane passing under the wheels, and parallel to the axis of the bore."

In the French Service—"But en blanc naturel, ou simplement but en blanc: le plus éloigné des deux points de rencontre de la trajectoire avec la ligne de mire naturelle. Portée de but en blanc: distance du but en blanc à la bouche de la pièce."*

"Dans les canons, le but en blanc est comme dans les armes portatives, la seconde intersection de la trajectoire et de la ligne de mire naturelle.

"La portée de but en blanc dépend de la grandeur de l'angle de mire naturel; elle varie pour les différents calibres et augmente ou diminue avec la charge qu'on emploie."†

The late General Dundas observes—"The but en blanc, in French nomenclature, is the range of the projectile from a gun, laid with the line of metal elevation, or angle

* Aide-Mémoire à l'Usage des Officiers d'Artillerie. † Piobert.

de mire, 800 yards being given as the range with that elevation, and one-third the weight of shot in powder as the charge: it is presumed that the dispart (Anglicè) of the gun is about 1°, which makes the power of the 30-pr. French and the 32-pr. English nearly equal. In the French Service the tangent scale or the hausse is divided for distances and not for any definite angle.

"The point-blank range of a gun, in the English Service, is the distance from the muzzle of the gun at which the projectile strikes the ground, after descending, by the force of gravitation, through a distance equal to the height of the muzzle above that plane on which the wheels stand.

"It is evident that there is much vagueness in the term 'point-blank range,' for guns are seldom on the same height of carriage, and therefore their range is unequal; moreover, it very seldom happens that the ground over which the projectile passes is a dead level: if fired over an ascending plane, the resistance of the projectile in passing out of the gun is increased, and over a descending plane diminished; consequently the ranges are increased and diminished."

It would seem that *point-blank* in the French Service, is purely an arrangement of the sight, whilst in ours it is considered to show the absolute power of the gun; but there are so many contingences connected with this power, such as windage, length of the piece, and thickness of metal, that any just comparison in pieces of ordnance is very difficult.

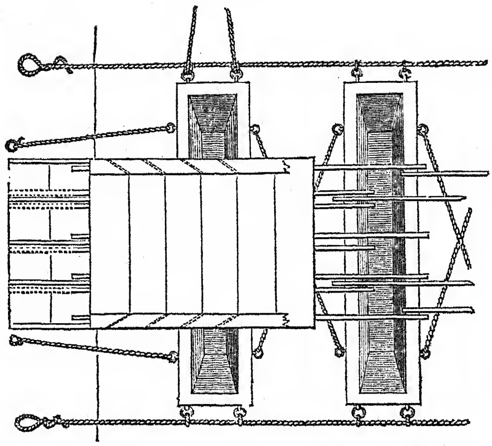
Practically, for all useful purposes, *point-blank* may be deemed as the line of no elevation or depression of a piece, whether *cannon, carbine, rifle,* or *musket;* and the *point-blank range* the distance which they will carry a ball without elevation or depression, varying according to its construction. This explanation applies equally whether the object fired at is either horizontal or upon an ascending or descending plane, if the line of no elevation be taken as parallel to the surface of the ground.

Every gunner, rifleman, or musketeer should ascertain the point-blank distance of his piece, or, in other words, at what range he can fire and hit the object or bull's-eye of a target, by a direct aim, without elevation or depression: the necessary elevation and the depression, not of much consequence, may be found by practice, or by reference to Tables of Artillery and Musket-ball Firing, given in this work.—G. G. L.

PONTOON.—The pontoon or metal open boat or punt with flat bottom, in the British Service, may be considered as obsolete: the word is retained in other forms, as Blanchard's Pontoons, India-rubber Pontoons, and General Pasley's Pontoons.

The pontoon was of metal over a frame-work of light scantling, tinned inside and out (see figure in the next page): the pattern is very old. It was used in all the wars in Flanders, and drawings of one may be seen in Müller's work on Artillery.

Although imperfect, heavy, and difficult of transport, the pontoon was the only resource for a Bridge Equipment with the armies under the Duke of Wellington, in his Peninsular and French campaigns, for the passage of rivers. These pontoon equipments formed a part of the Engineer Establishment in those countries, with a detachment of Royal Sappers and Miners, and a few seamen.



Part of a Pontoon Bridge.—Scale 14ft. to an inch.

Dimensions and Weight of Tin Pontoons. *

		Large Pontoon.			Small Pontoon.		
		ft.	in.		ft.	in.	
Outside measure.	Length at top	21	1		16	10	
	,, ,, bottom	16	8		13	4	
	Breadth	4	10		4	0	
	Depth	2	3½		2	0	
		cwt.	qrs.	lbs.	cwt.	qrs.	lbs.
	Weight of pontoon	9	1	24	6	3	16
	,, ,, appurtenances	12	3	9½	8	2	2
	,, ,, carriage	12	3	7	11	3	21
	Total weight	35	0	12½	27	1	11

Each pontoon had a carriage for transporting it, and the following appurtenances:

- 6 chesses for flooring
- 6 baulks, or beams
- 1 gang-board
- 2 oars
- 1 anchor
- 1 grapnel
- 1 pole
- 4 spring-lines
- 1 cable
- 1 sheer-line
- 1 boat-hook
- 1 maul
- 4 pickets, &c.

A Pontoon Train was composed of 36 pontoons, one-half of which usually formed a Bridge Equipment with our army in the Peninsular War.

Equipment.	Carriages.	Horses for each.	Total of Horses.
Pontoon carriages	36	6	216
Spare ditto	4	6	24
Forge waggons	2	6	12
Boats mounted on carriages	4	6	24
Waggons for tools	2	4	8
Carriages for stores	8	4	32
	56	...	316

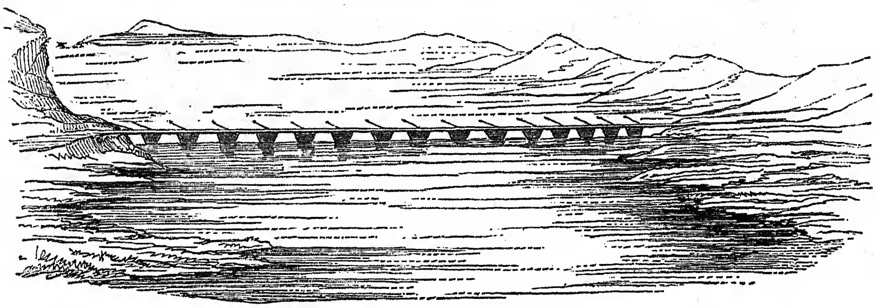
From General Sir Howard Douglas's work on Bridges.

With a well-arranged train of pontoons, and expert pontooners, the time to construct a bridge was at the rate of $1\frac{1}{2}$ minute for each pontoon.

Independent of their unwieldy nature, and the difficulty of transporting the old metal pontoons, as described above, they were only suited to tranquil streams, not subject to sudden floods ; for if any sudden rise of the water occurred, or if the river became disturbed by wind, they filled and went down.

A perfect Pontoon Bridge Equipment, combining facility of transport with the quick means of passing armies over considerable rivers, does not seem to have been yet organised.

See also articles 'Bridges,' and 'Passage of Rivers.'—G. G. L.



Pontoon Bridge—formed across the river Eslar, in Spain, in 1813.

New Canvas Pontoon.

Captain Fowke, R.E., has lately (1858) proposed a pontoon, for which he claims the following advantages over the cylindrical tin pontoon now in use, viz. :—Buoyancy nearly double ; weight less than half ; length on the march less than half ; first cost only two fifths ; bulk, when packed, one seventh ; height of roadway greater ; stability greater and side oscillation less ; durability greater and liability to damage less, whether from hostile shot, being rolled over stones, or grounding ; bailing out simple ; weight and number of parts of bridge diminished, and time of formation shortened ; capability of being used as a boat.

The pontoon is flat-bottomed, nearly rectangular in plan, with bow and stern like a Thames barge. It consists of stout canvas, waterproofed with boiled oil, stretched over a skeleton, formed of seven transverse frames, kept in place by two stretchers running the whole length, the space between being left open for bailing, &c. These stretchers are passed through holes in the stern transom and the loops on top of the frames, into sockets in the bow transom ; the canvas being stretched by means of a small screw-jack, and kept in place by keys through the transom and stretcher. Canvas is stretched over each frame, thus dividing the pontoon into eight watertight compartments.

Total length of pontoon 23 feet, *i.e.*, body 16′ and ends each 3′ 6″ ; breadth 4′ 6″, tapering to 2′ 6″ ; depth 2′ 3″.

For full description see R. E. Professional Papers, New Series, Vol. VII. 81.

C. R. B.

POSITION, MILITARY.—A *Military Position* is simply the extent of ground which an army occupies either for the purpose of engaging with an enemy, or of advancing to a combat.

The advantages which military positions should possess must have relation to some particular object; and if nature does not supply them, they should be supplied by art.

The object of a military position must be deemed defensive; and the natural consequence of the occupation of ground, whether permanently or for the moment, is to receive an enemy on the spot selected for the position.

The qualities necessary are—1. That the space occupied should be in proportion to the number of troops.—2. That the flanks should be covered by obstacles either natural or artificial, so that an enemy cannot act upon the wings or rear of the order of battle.—3. The field of battle must be open, and permit the movements of the troops; and the roads and openings in rear sufficiently clear to allow them to retreat, in the event of the position being forced.—4. The military features of the position should be chosen with such judgment, that an enemy cannot penetrate the line without running the risk of being taken in flank, and being beaten by an inferior force.

These qualities should be considered with reference to whether the army in position is for offensive or defensive purposes: if for the former purpose, a ready access in front is indispensable, and the means of advance open for offensive operations;—in the latter case, the auxiliary defence by field-works should be used as explained under the article 'Field Fortification;' and if the position be temporary, or likely to be so, by the enemy taking another line of offensive operations, when he has the means of so doing, the first part of that article will afford the information required how to fortify the position suitably to the occasion.

If the position is occupied for the purpose of covering a country effectually, so that it should be secure during the War, or a frontier or line of country, or the capital of a territory, the defensive measures should be adopted as recommended in the second part of the article 'Field Fortification,' and in the Appendix to it.

There are three good examples applicable to permanent positions worthy of attention:

1. The defence of Provence in the early part of the 18th century, by Marshal Berwick.
2. The defence of Ardennes by the Republican army in 1792, by General Dumourier.
3. The defence of Lisbon by the Duke of Wellington in 1810, called the 'Lisbon Lines.'

One of the most difficult questions is to define the number of troops necessary to defend a given spot. The position in front of Lisbon, extending upwards of twenty miles, was not occupied by a larger force than that at Waterloo, which did not cover three miles; in fact, it is a practical one in reference to the nature of the ground, and purely tactical.—G. G. L.

POSITION, RETRENCHED.*

"Ceux qui proscrivent les lignes, et tous les secours que l'art de l'ingénieur peut donner, se privent gratuitement d'une force et d'un moyen auxiliare jamais nuisibles, presque toujours utiles et souvent indispensables."

"Until recent experience, it was fast becoming an axiom, that an army receiving battle in position must be beaten, and that no skill in occupying and strengthening, nor firmness in disputing and maintaining ground, could balance the advantage of free and concentrated movement, and the moral confidence arising from being the assailant. * * * *

* From 'Memoranda relative to the Lines of Torres Vedras;' in 'Journals of Sieges,' by the late Major-General Sir John T. Jones, R.E.

"It is, however, unnecessary to revert to past history to show the value of field-works, as in the recent battle of Borodino, a few simple redans, hastily thrown up to cover the left flank of the Russian position, paralysed for hours two French corps d'armée, and had nearly proved equally fatal to the fortunes of Napoleon as the redoubts at Pultowa to those of his prototype Charles. Indeed, the attack of Dresden, which failed in consequence of the assailants being opposed by a slight field retrenchment, and many other events of the recent campaigns, leave no doubt that field-works judiciously disposed may still be rendered valuable auxiliaries, even to the most numerous and most active armies.

"To effect this, and apportion works justly to cover a country, or strengthen a proposed field of battle, is the most difficult application of the Engineer's art, being subject to no fixed rule, but merely founded on general principles, requiring to be modified on each occasion from an innumerable variety of circumstances, both physical and moral.

"A just idea of these principles can only be acquired through a knowledge of tactics, and of the powers of troops under different orders of formation and movement; which, well understood, can scarcely fail to produce a feeling that works ought in every situation to be accessories and aids to the manœuvres of troops, and never principals of any defensive field system.

"Posting troops to fight a general action, or strengthening the front of an army when so posted, are details founded on the foregoing principles, which for the same reasons scarcely admit of theoretic elucidation, and the knowledge of them can only be fully attained by long service with an active corps.

"Considerable insight into such details may, however, be gained by studying the principles on which various fields of defensive combat have been occupied by skilful Commanders.

"In these it will be seen that a rocky height, a knoll, a wood, a village, and even a single house, have frequently formed the prominent flank or defensive posts; and instances might be adduced where each of the above obstacles have mainly contributed to the repulse of the assailants; and on the contrary, where such posts, injudiciously occupied or ill-supported, have led to discomfiture or the loss of entire divisions of the defensive force. * * * *

"There is, however, a very serious obstacle to the employment of the art of retrenching positions, which is, that after an army has taken up its ground, and a battle becomes inevitable, there is seldom time to throw up works of sufficient strength to be depended upon; and it is scarcely possible, in any moderately open country, to select a position to be fortified in advance for the protection of a frontier or a capital which an enemy will not find roads to turn and render useless. Thus, in allusion to the battle of Waterloo, had the ground been strongly retrenched during the spring, Napoleon would naturally have avoided it by marching on Brussels by the road of Hal, and therefore such preparatory labours seem only advisable in peninsular situations, or to block up the entry, or dispute the sortie of a mountain-pass, occupy the interval between two fortresses, or for some other specific and very limited object.

"Even in such favourable situations, attention should be directed rather to the improvement of natural obstacles than to the erection of artificial lines of defence;* and where works cannot be dispensed with, they should, as far as practicable, be enclosed, independent, and capable of defending themselves. Nothing can be more vicious than to cover an extensive tract of country with a regular system of bastions and redans, as recommended in most Treatises on Field Fortification. Such long

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* See article 'Field Fortification.'

systematic lines of defensive works, besides the great expense, labour, and publicity attending their formation, have the serious defect of being of no strength, unless equally guarded throughout; and further, when attacked, the defenders have, in consequence of their flanked trace, to man an alignment of nearly double the length of the front to be defended, and are utterly incapacitated from making any instantaneous or powerful forward movement: they therefore necessitate the worst possible disposition of troops for offence or defence, and must be regarded as inadmissible under the present system of tactics. Indeed, such long defensive lines, even when most in repute, at the end of the seventeenth and commencement of the eighteenth century, were invariably forced as often as attacked, and it is difficult to conceive on what foundation their popularity so long sustained itself.

"Field defences, however, are not to be indiscriminately condemned or rejected because they are continuous or systematic. In order to strengthen the front of an army with judgment, it is necessary to consider every feature and every portion of the ground separately, and arrange such mode of occupation as shall best combine its particular defence with the general defence of the position. Thus, in parts unfavourable for manœuvring, it may be advisable to form a continued line of considerable extent, covered with every nature of obstacle, and having none but the most confined outlets, on the principle that a range of difficult heights would be scarped, or low ground inundated, to lessen the number of men on those points, and leave a superabundance of force for other points favourable for offensive movements. Again, since the employment of artillery in masses has been introduced, and that an irresistible fire, sometimes of hours' duration, now invariably precedes the advance of the columns of attack, it will frequently prove a good measure, in situations where natural cover cannot be formed from a cannonade, to create it artificially between all the prominent defensive posts.* Thus, each furlong of ground being duly considered, and the nature of defence best adapted to the locality being formed, the whole front of an army may occasionally be covered with lines of works, which, while they augment its defensive powers, leave its movements perfectly free.

"Continuous lines, of the short extent of a mile or two, may frequently be resorted to with advantage, in situations where the flanks can be naturally or artificially secured, as on a river or a fortress.

"Such lines, in communication with a fortified town, when composed of fronts of fortification or other flanked trace, and made of a profile not to be assaulted, are well suited to facilitate the defensive manœuvres of an inferior army, and also to augment the defensive powers of the fortress itself, by occupying important tracts of ground which could not be included within the permanent works. In such cases they are usually denominated Retrenched Camps,† under which character they form a medium of defence between field-works and permanent fortifications, which can be resorted to on any pressing emergency arising from defeat, and may be generally recommended by an Officer without hesitation; for if it be not convenient to man them fully, their evacuation, after a show of resistance, neither compromises the retreat of the defenders, nor detracts from the original strength of the fortress.

"Experience affords many proofs of positions of two or three miles length of front, which could not be turned when retrenched on a field profile, being capable of an excellent defence. * * * * *

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* "This might be effected by means of a sunken trench, like a parallel at a siege, made to connect a whole chain of redoubts. Such an expedient would cover infantry from the fire of guns without impeding their forward movement in line, and openings might be left for the advance of the cavalry and artillery, or they might act in masses on the flanks."—*Author.*

† See 'Camp, Intrenched,' vol. i. and Plan.

"It is apparent, however, that isolated and unsupported field positions of this nature, retrenched on a field profile, besides being liable to be turned, and the defenders shut up as in a trap, and made prisoners, partake of all the defects of longer continued lines in proportion to their extent, and are in the same proportion objectionable. * * * *

"None of these objections to continuous lines, however, apply to retrenchments formed of enclosed and isolated works, each capable of a good resistance, as the intervals between them do not require a line of supporting troops; and after furnishing garrisons for the works, the army may remain in masses, sheltered from cannonade by some irregularity of the ground near the summit of the heights; or if such be not found, on their reverse, immediately below the crest, ready to move in compact and formidable bodies on any menaced point, or form into line or manœuvre on the posts taken up, so as best to parry the efforts of the assailants.

"It seems to be an indispensable condition of such field-works in aid of an army, whether prepared at leisure or during active operations, that they be of a profile and capability of defence to resist an assault,—that they be securely closed in the rear, placed sufficiently near to and so disposed as to flank each other, and armed with sufficient artillery to prevent heavy columns passing between them without being thrown into disorder from severe loss; or else made of a size to contain a force likely to prove formidable to the rear of a column which should venture to pass them. In this case, indeed in all cases, the outlets from, and intervals between works, should give every freedom for the movement of troops compatible with security from assault or being passed.

"On this point it may be as well to observe, that detached enclosed works, in front of an inferior army acting on the defensive, ought to be regarded as vital points, performing certain functions of themselves, and their garrisons be considered as integral parts of the works, destined to share their fate—to triumph or fall with their post, and not as portions of the army to be protected and withdrawn. Under this view, the defensive corps being left unshackled in their movements, and their part being confined to the discomfiture of the enemy, they will be prepared to seize the favourable moment, and advance to the attack when the redoubts shall be most warmly engaged, or their fire have thrown the assailants into confusion; so that to derive full benefit from works, as much judgment is required in posting and manœuvring the force to be strengthened, as in placing the works themselves.

"This leads to a consideration of the just proportion between the garrisons of detached works and the army they cover, and also of the length of front along which works may be allowed to extend for given numbers of men. On the first point it may be observed, that the better the troops composing the defensive army, the fewer should be the works, for it can seldom be advisable to confine any considerable body of a manœuvring and steady force in an enclosed work, unless it be the key or main support of a position; but when an army is composed in great part of ill-disciplined and unsteady troops, artificial defences can scarcely be too numerous.

"The extent of front which works may cover need in strictness only be limited by the power the army possesses of succouring, in sufficient time, any and every work that may be pressed, so that a ready or difficult communication will frequently decide the eligibility of occupying a distant point; but as strength is invariably gained by concentration, no ground should be occupied that is not intimately connected with the main object of defence, even if invitingly convenient. On this head no better rule can be followed than to inquire, previously to occupying any point, whether it be essential to the support or safety of the main body of the army; and on each occasion an Officer must exercise his judgment to modify and turn local circumstances

to advantage on the unchangeable basis of science. It cannot, however, be too strongly borne in mind by those planning defensive expedients, that troops are the principals, works the accessories of defence,—that the latter must invariably be dependent on and limited by the former, and consequently that every point superfluously retrenched is an unnecessary source of distraction and division of force. Field-works can never without hazard be left to their own garrisons; and reverting to the Lines of Torres Vedras, which would seem to warrant the creation of an unlimited number of defences, it may be confidently predicted that any Commander not possessing the utmost promptitude, decision, and skill in manœuvring troops, who, trusting to that example, shall attempt to defend against a superior, or even equal force, a tract of four-and-twenty miles of country as a fortified position, will infallibly be beaten; and that an Engineer who should, on any ordinary occasion, copy the extended system of isolated redoubts and retrenchments practised in front of Lisbon, would, instead of adding to the strength, altogether cripple an army.

"But whenever, by the foresight and skill of the General, and the exertion of the Engineer, the arrangements of the troops and works shall be in happy unison, and a defensive army well posted shall have its front covered with works constructed on just principles, its force will be incalculably augmented, and its defeat rendered almost impracticable. Even a few works, thus judiciously disposed on the principal features of the ground, or to sweep the approaches, could not fail to add materially to the powers of movement and resistance of a defensive force; as will frequently the most trifling efforts of labour, such as loopholing buildings, barricading streets, blocking up or opening communications, destroying bridges or roads, or the fords of a river, felling abattis, forming emplacements for field-guns, or the slightest cover from cannonade; and an active and zealous Engineer will generally find opportunity on the eve of a battle to strengthen, by some of these various labours, the fronts and flanks of a defensive force.

"In making this statement, it is not forgotten that since the improved organisation of armies has given them an increased facility of movement, and a consequent celerity and boldness of enterprise, placing legs almost on an equality with arms in war, time is rarely allowed to a defensive force for perfecting defensive expedients; but this consideration, so far from being deemed to excuse the attempt, should only stimulate an Engineer to increased exertion. * * * * The most simple exercise of his art will occasionally prove its paramount utility; and as it not unfrequently occurs, even after hostile armies come into view, that days pass in reconnoitring or preparation for attack, who can say on such occasions to what extent activity and intelligence may not gain artificial strength for a field of defensive action, and consequent character and reputation for an Officer?" *

PRISONS, MILITARY: DISCIPLINE AND MANAGEMENT.†—The question of Military Imprisonment having engaged much public attention during previous years, was very fully inquired into by Commissioners appointed for the purpose in 1835 and 1836: little, however, was done at the time to give effect to their recommendations; but the late Lord Hardinge, on assuming office as Secretary at War in 1842, proposed to his Grace the Commander-in-Chief that a Committee should be appointed to investigate the subject, and report their opinion on the means

* See article 'Fortification, Field,' vol. ii.

† By Major-General Sir Joshua Jebb, K.C.B., Royal Engineers, Inspector-General of Militar Prisons.

of carrying into effect a regular system of Military Imprisonment as a substitute for the general infliction of corporal punishment.

A Committee, of which Lieut.-General Earl Cathcart was President,* was appointed accordingly, and received their instructions from Sir James Graham, Secretary of State for the Home Department. The chief points to which the attention of the Committee was directed were the following :

Whether it might not be desirable to mature for the future a permanent scheme as regards the establishment of prisons, in which military offenders alone shall be confined, and in which they might be subjected to the discipline and punishment best suited to their military habits, and to the nature of their offences.

Whether any and what changes were required to be made in the Mutiny Act, with reference to this subject.

Whether, without any change in the law, a system of military punishment might not be laid down which would adapt itself to the greater portion of the cases of soldiers sentenced to confinement for military offences. Whether drill, breaking stones, or other hard labour, might not be substituted for confinement in civil gaols.

The Committee were to report upon the nature of the confinement, the system of drill, the hard labour, the diet, the clothing, the bedding of the prisoners. They were also to take into their consideration the powers to be given to the Officers in charge to repress refractory and insubordinate conduct amongst the prisoners, whilst undergoing their sentences ; and who in their judgment should be invested with the superior powers of Visiting Justices, and exercise superintendence and control.

The Committee commenced their sittings early in the spring of 1844, and continued them till the end of June in the same year. Their views on the means of effecting the proposed objects were as follow :

With reference to the provisions to be made in the Mutiny Act for establishing Military imprisonment, clauses were proposed for empowering the Secretary at War to establish military prisons, and appoint visitors and officers, &c., and to confer upon him generally the same powers that are vested in any of Her Majesty's principal Secretaries of State, with respect to civil prisons. Another clause was proposed for the purpose of giving to the Superior Officer in command, whose duty it might be to confirm the sentence of a court-martial, the power, which he did not previously possess, of selecting the place, whether a civil gaol or a military prison, in which the offender should be confined, and from which he might at any time remove the prisoner, in order that the prisoner might undergo the remainder or any part of his sentence in some other public prison or place of confinement : henceforward, therefore, courts-martial do not, in their sentences, notice the place of imprisonment.

With reference to the question of establishing prisons in which military offenders alone might be confined, and in which they might be subjected to the discipline and punishment best suited to their military habits and the nature of their offences, the Committee took into consideration the minute of Sir Henry Hardinge, dated the 24th of May, 1842, the Report of 1837 of the Home Inspectors, and the opinions of various military authorities referred to in these and other documents; and they thus expressed their opinion :—"That assuming, *in limine*, the concession to public opinion of the general disuse, though not total abolition, of corporal punishment, and

* The following were the members of Lord Cathcart's Committee: Colonel Grant, commanding Grenadier Guards ; Colonel Godwin, late commanding 41st Regiment ; Majo Jebb, R.E., Surveyor-General of Prisons ; Rev. D. Nihill, late Chaplain of Millbank Penitentiary

feeling the insuperable difficulty of devising any new satisfactory penalty, repressive of crime in the Army, the Committee considered they had no alternative but a choice between civil and military prisons, and they could not hesitate to prefer the latter, and to come to a decisive conclusion in favour of a permanent scheme as regards the establishment of prisons exclusively for military offenders."

They go on to say, that in considering the subject generally, there were two species of punishment to be provided for, viz., solitary confinement, and imprisonment with hard labour.

In reference to the former, they did not propose any change in the principle of the existing law, but merely suggested an amendment which was incorporated into the Mutiny Act, for enabling courts-martial to sentence prisoners to solitary confinement, (not only, as formerly, to periods not exceeding one month at a time, or three months at different times with intervals of not less than one month,) but also for *shorter periods*, with intervals of imprisonment with hard labour of not less duration than the periods of solitary confinement.

Classification of Prisoners.—With respect to sentences of imprisonment with hard labour, or mixed sentences involving periods of hard labour alternating with solitary confinement, the Committee recommended associated labour under a rule of silence in preference to what is technically called 'the Separate System,' but upon this they grafted a principle of classification to which they attached considerable importance.

To any one conversant with the operation of this principle in ordinary prisons, and with a knowledge of its having been repudiated by the best authorities on prison discipline, it will at first sight appear extraordinary that the attempt should be made to revive it in military prisons. It is necessary, therefore, to explain that *classification* under the Gaol Acts is based upon the *crime* for which a prisoner happens to be sentenced, by which any one frequently re-committed for different offences may find himself alternately associated with felons or misdemeanants, or others, as the case may be: this affords no moral standard by which to make a classification, and therefore leads to much practical evil.

The classification recommended by the Committee, on the contrary, is based upon *character*, and will be best understood by the following rule:

"The Governor will bear in mind that the object of classification is, first, to protect the young soldier, and the less hardened offender, from the mischievous consequences of association with worse characters; and secondly, to hold out an inducement to all the prisoners to behave well in prison, by the hope of reward and the fear of punishment, in being either promoted to a higher class, or degraded to a lower one. In applying this principle, the worst characters, such as have been convicted of 'disgraceful conduct,' or who may appear to be confirmed drunkards, or incorrigible and hardened offenders, and prisoners who have ever been subject to corporal punishment, would obviously be placed, on reception, in the third class.

"Those prisoners who do not come under this description, and of whom better hopes may be formed, will, as an invariable rule, be placed, on reception, in the *second class;* but the Governor will exercise his discretion in making an early selection for promotion to the *first class* of any prisoner, who, from the nature of his offence, and previous good character, appears deserving of such distinction, or who, from his youth or other circumstances, requires to be protected from the bad effects of associating with worse characters.

"The *first class* shall be composed of those prisoners who, from their quiet, orderly habits and general good conduct under punishment, may appear deserving of being promoted from the *second class*, after some experience has been gained of their characters.

"In like manner, prisoners in the third class will, by good conduct, be eligible for promotion to the second class.

"Prisoners in either the first or second classes will also be liable to be removed to a lower class for misconduct.

"The classes will be distinguished by badges marked as first, second, or third class. attached to some conspicuous part of their prison-dress."

The difference in treatment between the first and second classes is, that the former are generally exempted from shot-drill, and, during the hours prescribed for that exercise, are employed under a warder of the Royal Artillery in working heavy guns, or in labour not of a penal character. They have also a meat dinner on Sundays, and the silence enforced on other classes during the evening is relaxed, and they are permitted to converse in an orderly manner.

The distinction between the second and third classes consists in the former being exercised with 24lbs. shot, while the latter carry 32lbs. shot. The second class also receive school instruction from 6 to 8 o'clock in the evening, whilst the third class are employed in picking oakum.

These distinctions between the classes may appear trifling, but experience has shewn, by the endeavour that is generally made to obtain the advantage of promotion to the higher class, that they possess the required influence.

Hard Labour.—With respect to hard labour, the Committee were of opinion that it was an object to avoid any description of labour or exposure which had a tendency to *degrade* the soldier. With this view they objected to the use of the tread-wheel, and to the employment of prisoners in gangs outside the prison; and in lieu of these ordinary methods of enforcing sentences of hard labour, they proposed piling and unpiling heavy shot, knapsack drill, working heavy guns, or other such employment.

Diet.—With respect to diet, it was recommended that it should be such as would maintain the prisoner in perfect health, so that on rejoining his corps, he should be fit for immediate duty. They, however, strongly urged their opinion that no comfort, not essential to health, should be allowed, and that a prisoner should be made to feel, during the whole period of his confinement, that his state, and condition was, in all respects, much worse than when doing duty with his regiment.

Governor and Subordinate Officers.—On the subject of the officers to be appointed to the charge of the Military Prisons, the Committee were of opinion that, "considering the extent of the prisons, the power to be vested in the chief Officer, and his responsibilities, the Governor ought to be a Commissioned Officer; and that an Officer possessing the qualifications of a good Adjutant would be the most suitable for the situation."

They conceived it to be an object to retain the advantages of that chain of responsibility which exists in the Service, and therefore recommended that the chief warder, or second in command, should be of the grade and possess the qualifications of an effective segreant-major; that the warders should be of the grade of colour-sergeants; and their assistants of sergeants and corporals to be taken from the Pension List.

Visitors or Governing Bodies.—With respect to the general superintendence of the military prisons, the Committee suggested that visitors should be appointed by the Secretary at War, and a power to that effect was given by the Mutiny Act.

They were of opinion that the following Officers would be suitable as visitors to Military Prisons:—

The General, or the Officer commanding the district or station;
The Assistant Adjutant-General;
The Assistant Quarter-master-General, or the Brigade-Major;
The Garrison Chaplain;

The Principal Medical Officer ;

The Commanding or Field Officers of regiments or corps in the district or station for the time being ;

and such other persons as the Secretary at War might appoint.

Duration of Imprisonment, and Expense.—With reference to the duration of imprisonment, the Committee observed, that under the law as it then existed, district and general courts-martial had an unlimited power with respect to the periods for which they might award imprisonment, (excepting in the case of solitary confinement,) and that the effect was sometimes to extend a man's imprisonment, and consequently his absence from duty, to one, or even two years. It is very generally admitted that the punishment of imprisonment, if too long protracted, loses much of its mora effect, from the prisoner's becoming callous to his situation, and no sufficient advantage is therefore gained to compensate for the evil of his being so long absent from his regiment. The Committee therefore recommended that the actual detention of a soldier in prison should not exceed six months, except by sentence of a general court-martial.

On the question of the expense of maintaining the Military Prisons, the Committee stated their opinion, that the saving accruing from the stoppage of the soldiers' pay might probably cover the whole expense of carrying into effect an improved system of discipline, which could not fail to be of advantage to the Service.

Regimental Imprisonment in Garrison or Barrack Cells.—With respect to the very important question of regimental imprisonment in garrison or barrack cells, the Committee strongly urged the expediency of establishing some efficacious means of repressing, by salutary punishment, those minor offences, which, for want of due coercion, prove in numerous instances the precursors of more serious delinquency, and stated their opinion that the power then possessed by Commanding Officers of regiments was inadequate for the purpose. With this view they strongly recommended that a proportion of properly constructed cells should immediately be provided at every barrack station in Great Britain and Ireland ; that provost-sergeants, selected from the effective strength of the respective corps, should be appointed in every regiment, to take charge of the prisoners in the cells, and to be otherwise employed, under the orders of the Commanding Officer, in the police duties of the barracks ; and that Commanding Officers should in future have the power to imprison soldiers, on their own authority, for minor offences, for a period not exceeding *seven* days, accompanied by a stoppage of pay, with the exception of a sum not exceeding 6*d.* a day to be drawn for subsistence. They observed with reference to the stoppage of a soldier's pay when undergoing imprisonment by order of a Commanding Officer, that it was justified on the equitable principal, that when a man by misconduct disqualifies himself for the performance of duty, he cannot justly claim that pay to which the performance of duty can alone entitle him.

The Committee, at the same time, drew up a set of rules specially applicable to soldiers undergoing regimental imprisonment in the barrack cells, and for the guidance of the provost-sergeants in the performance of their duties.

They also recommended that sentences by courts-martial for periods not exceeding forty-two days, should be carried into effect in the proposed barrack cells ; but that all prisoners sentenced to longer periods of confinement should undergo their punishment in the district military prisons, where a more suitable staff, and a more corrective and reformatory discipline, could be maintained, than it would be possible to establish in very small prisons.

Encouragement to Well-conducted Soldiers.—The Committee offered their opinion upon this important subject in the following terms :

"The encouragement of the well-conducted soldier is no less conducive to the good order of the Service than the punishment of the bad. With a view to this object, the Committee would recommend, that every soldier who has been actually serving and doing duty with his regiment in the ranks, shall, at the expiration of nineteen years of uninterrupted good conduct, and being in possession of two good-conduct badges, and the additional pay corresponding thereto, of which he has never been deprived for any misconduct, be entitled to all the privileges now enjoyed by a Waterloo man; namely, to have two years added to his service, and the immediate benefit of this addition as respects his receiving the third good-conduct distinction and pay, which would otherwise have been due only after twenty-one years' service, and prospectively as it will affect his claim to additional pension on discharge."

Steps taken for establishing Military Prisons.—The foregoing were the chief recommendations of Lord Cathcart's Committee, and instructions were immediately issued by Sir Thomas Freemantle, who had succeeded Sir Henry Hardinge as Secretary at War, for giving effect to them. Arrangements were made for converting Fort Clarence at Chatham, Southsea Castle at Portsmouth, and a portion of the extensive Ordnance Stores at Weedon, into three district Military Prisons; and as soon as the necessary works could be completed under the direction of the Royal Engineer Department, officers were appointed, and the prisons were occupied.

A large block of garrison cells having been previously erected at Devonport, was subsequently converted into a Military Prison, and four prisons were thus established in England.

The hospital attached to the barracks at Greenlaw, near Edinburgh, was at the same time converted into a Military Prison for Scotland.

With respect to Ireland, the then existing Provost Prison at Dublin, the prison at Limerick, which had been brought into a very effective state under the direction of Colonel Mansell, and the cells at Cork and Athlone, were brought under regulations issued by the Secretary at War, and established temporarily as Military Prisons for Ireland.

Preparations were at the same time made for converting the black holes and dry rooms attached to most guard-rooms into cells of a size and construction proper for the enforcement of a regimental system of imprisonment, under regulations issued by the Commander-in-Chief.

Suitable quarters for a provost-sergeant were added to the blocks of cells which had been built. Others were erected on an improved and more economical principle of construction; and means were thus afforded in a comparatively short time, for giving effect to the provisions of the Mutiny Act, as regarded regimental imprisonment, and the increased power conferred upon Commanding Officers.

General Statistics.—The Military Prisons at home are the following:—

England.—Chatham, Gosport, Weedon, Devonport, Aldershot.
Scotland.—Greenlaw, near Edinburgh.
Ireland.—Dublin, Cork, Limerick, Athlone.

In all, ten prisons in the United Kingdom.

At foreign stations, the following prisons are established:

Gibraltar, Quebec, Halifax, Barbados, Bermuda, Mauritius, Vido for the Ionian Islands, and St. Elmo at Malta.

The following are the principal statistics of the Military Prisons at home, omitting Aldershot, for the seven years ending 1855 :—

	1849.	1850.	1851.	1852.	1853.	1854.	1855.
Total number of prisoners admitted . .	3,533	3,565	3,266	3,313	3,331	3,307	5,322
Proportion per cent. of those admissions to the force . . .	5·36	5·06	4·66	4·57	4·47	4·78	4·48
Daily average number of prisoners in confinement throughout the year . . .	750	659	550	542	570	504	562
Proportion per cent. of the average numbers in confinement to the force	1·13	0·93	0·78	0·74	0·76	0 73	0·47
Average length of sentences	99 days	94 days	95 days	92 days	92 days	87 days	77 days
Punishments inflicted by Visitors for serious offences, *viz.*— . .							
Corporal punishments . . .	11 550 lashes	11 495 lashes	6 300 lashes	6 250 lashes	6 238 lashes	4 125 lashes	5 175 lashes
Sentenced to solitary confinement	15	15	10	8	17	10	6
Sentenced to separate confinement	33	20	6	9	9	4	9
Sentenced to be put in irons . . .	2	6	1	1	2	1	1

The following is a statement of the ages, services, country, and religion of the prisoners admitted in the years 1849 to 1855 inclusive :—

	1849.	1850.	1851.	1852.	1853.	1854.	1855.
Ages.							
Under 20 years . . .	575	386	317	350	621	962	1,577
From 20 to 30 years . .	2,446	2,585	2,415	2,344	2,189	1,937	3,185
,, 30 to 40 years . .	482	565	504	580	487	395	528
Above 40	30	29	30	39	34	13	32
	3,533	3,565	3,266	3,313	3,331	3.307	5,322
Services.							
2 years and under . .	986	761	531	651	986	1,580	3,902
Under 7 years . . .	1,554	1,656	1,669	1,531	1,291	884	692
From 7 to 14 years . .	798	928	849	841	813	636	512
,, 14 to 21 years . .	171	209	200	260	211	193	188
Above 21 years . . .	24	11	17	30	30	14	28
	3,533	3,565	3,266	3,313	3,331	3,307	5,322
Country.							
English	1,873	1,992	1,840	1,737	1,902	1,817	2,983
Scotch	405	316	313	476	424	342	557
Irish	1,255	1,257	1,113	1,100	1,005	1,148	1,742
	3,533	3,565	3,266	3,313	3,331	3,307	5,322
Professed Religion.							
Protestant	2,121	2,260	2,063	1,977	1,937	2,028	3,263
Presbyterian . . .	325	258	246	391	468	247	344
Roman Catholic . . .	1,087	1,047	957	945	926	1,032	1,715
	3,533	3,565	3,266	3,313	3,331	3,307	5,322

Expenditure.—The following is a statement of the expenditure on account of the Military Prisons during the eight years ending 1855 :—

Expenses incurred.	1847.	1848.	1849.	1850.	1851.	1852.	1853.	1854.	1855.
	£	£	£	£	£	£	£	£	£
The total charge for pay and allowances of prison officers, and for the subsistence and washing of the prisoners, was	13,741	14,801	14,106	13,291	12,451	12,598	13,488	14,359	15,933
The full pay and beer money of prisoners in confinement not issued amounted to	13,310	16,171	15,543	13,738	11,329	11,390	11,925	9,999	13,868

Effects of the Discipline.—Having adverted to the principle as well as the details of the discipline enforced in the Military Prisons, and brought forward such facts as will throw a light on the general operation of the system, I would observe that, so far as an opinion can be formed of the state of discipline in the army by the amount of punishment, the results exhibited in the first return inserted at page 148 are encouraging and satisfactory.

The facts may be thus stated :—In 1843 the number of soldiers imprisoned at any one time under sentence by courts-martial in civil prisons, exclusive of those who might be in confinement by order of Commanding Officers, were in the ratio of 20 in 1,000.

In the five years from 1847 to 1851, after the Military Prisons were brought into operation, the average number in confinement, including also those in barrack cells, by order of Commanding Officers, amounted to little more than 14 in 1,000. During the following three years, from 1852 to 1854, the number was still further reduced to about 11 per 1,000. In 1855 it was only 7 per 1,000, but this falling off may be attributed to the bulk of the army being in the East.

The diminution in the number undergoing imprisonment for serious offences is the more deserving of attention, when it is remembered that this mode of dealing with military offenders has almost superseded corporal punishment.

Discipline.—The discipline now in force in the military prisons is in all respects in conformity with the recommendation of Earl Cathcart's Committee, and has, on the whole, worked in a satisfactory manner. In reviewing the subject, it will be seen that, by the prompt measures taken by the Secretary at War for giving effect to the Report of the Committee, the practice of committing soldiers to civil prisons soon became almost unnecessary. The gaols were thus relieved from a serious and inconvenient pressure; the soldier was not degraded by being placed by the side of a felon, and taunted by him as being on the same level; he was also spared the public exposure of being committed to a common house of correction, and at the same time was subjected to an effective punishment better adapted to his habits, and more likely to secure the objects for which he was sentenced.

Another great advantage was gained. The system of discipline in all Military Prisons is perfectly *uniform*, whereas, when prisoners were indiscriminately committed to civil prisons, there was the greatest uncertainty as to the degree and nature of the punishment which would be inflicted. But few prisons could be selected in the whole country where uniformity of discipline prevails. In some, the greatest strictness and severity is found, in others, the greatest mildness and laxity; in some, the strictest separation, in others, the most unrestricted and contaminating association; nothing, in fact, being so different as the degree of punishment inflicted in different prisons. The means of maintaining discipline, therefore, so far as it depended upon

efficacious punishment for the repression of crime, was thus a matter of chance, influenced in a great measure by the character of the discipline in the nearest prison.

The primary object for which the regulations for the Military Prisons have been framed has been to repress crime in the Army, by creating a salutary dread of a prison; and subordinate to this object has been the prevention of the repetition of crime by the same individual in the endeavour to reform him.

It will be admitted by all, that punishment and reformation are the main objects of penal discipline, and the question to be considered is, the due adjustment of these elements.

In the routine of discipline which has been established, the prisoners are under strict superintendence and control, from 6 o'clock in the morning till 8 o'clock at night, and have a fair share of hard labour to perform, consisting of shot exercise, drill, picking oakum, breaking stones, &c. In those prisons where separate cells are provided, each prisoner takes his meals alone and sleeps in his cell. In other prisons which were converted from existing buildings, the prisoners are associated at meals, and sleep in large rooms or bomb-proofs, but night and day they are under close supervision, and the strictest silence is maintained on all occasions.

If this routine be compared with the ordinary discipline of civil prisons, it will be found that although the hard labour is of a less degrading character, it is fully as severe.

As regards the reformation and welfare of a prisoner, the Governors are enjoined to bear in mind, that the chief object of establishing a prison exclusively for military offenders is to maintain discipline in the Army; and as punishment alone can hardly be expected to produce this effect, he should consider it his duty to endeavour to instil soldier-like and moral principles into the mind of every prisoner, letting him see that he takes an interest in his welfare, and, by his good advice and kindly admonition, endeavouring to convince him of his error, and to encourage him to aim at future good conduct, and the attainment of a respectable character in the Service.

The Chaplain also is directed to endeavour, by all the means in his power, and particularly by encouraging their confidence, to obtain an intimate knowledge of the character and disposition of all the prisoners: for which purpose he shall occasionally see and converse with every prisoner in private; and whenever he shall wish to instruct or examine a class of prisoners, he shall apply to the Governor. He shall establish an evening school, and frequently attend and examine the prisoners as to their progress, and give directions concerning their instruction; and he is expected to allot a considerable portion of his time to visiting, admonishing, and instructing the prisoners in their cells and rooms.

Among soldiers, as in all other bodies of men, there are to be found reckless and incorrigible characters, who can neither be subdued by punishment, nor encouraged to good conduct by kindness and forbearance; and it is very generally admitted, that repeated and lengthened terms of imprisonment fail in their effect with such men from their becoming habituated to the confinement, and thus ceasing to have any dread of it. During long periods of confinement there is also a great loss of service, a constant additional duty is thrown on the well-conducted soldier, and discredit is brought upon a regiment by the misconduct of, it may be, a very few men. Such characters are worse than useless in the Service, and it is the opinion of many officers, that after repeated trials, they should be marked so as to prevent re-enlistment, and then be discharged.

The advantage of this course, in the cases of hardened and incorrigible characters, cannot be doubted; for whatever expense may have been incurred in training the soldier, no service is afterwards rendered to compensate for it. On the other hand,

however, it must not be forgotten, that if the discharge of all such men were to become an established practice, and that great facilities for getting rid of them were afforded, it might operate with some as an inducement to commit crime with a view to obtain a discharge.

Several Officers have expressed their opinion, that the discipline of Military Prisons is not sufficiently stringent and severe; that the comfort of the prisons, the facilities for cleanliness, the good diet, the bedding and warm clothing, and the advantages of being every night in bed, contrast favourably with the discomfort of many barracks and half-billet stations, and with the onerous duties, especially during inclement weather, that fall to the lot of soldiers serving with their regiments: others, who take a warm interest in the welfare of the *individual*, would advocate less hard labour and more instruction.

This question is of paramount importance. In considering it, however, it is necessary to keep in mind the different objects which are to be attained, in order that we may not lose sight of their relative proportions, and be carried away with the one idea of either punishment or reformation.

The repression of crime by corrective discipline depends mainly on the punishment operating widely *as an example*, and thus exercising a deterring influence on others, and in a minor degree by the individual himself being deterred from future offence from fear of the consequences, or by his being so reformed that he ceases to commit crime from a better motive than that of fear.

The first of these objects will be promoted by carrying into effect a system of discipline known to be of a severe and stringent character, such as will make men prudently resolve to keep clear of it if they can. It should also dwell on the memory of one who has once been subject to it, as a disagreeable and certain consequence of crime, and thus tend to prevent its repetition.

At the same time, however, that a severe discipline with more extended objects is maintained, there can be no doubt that efforts should be made to prevent the repetition of crime by an endeavour to reform the individual.

With the few hardened reckless characters that are to be found in every regiment, reformation is a very hopeless task; but with young soldiers under two years' service, and with many under sentence for 'desertion' and 'absence without leave,' (and these constitute the majority,) such a course cannot fail to have its effect.

Among other things, it has been suggested, that it would be of advantage to turn the labour of the prisoners to account, by placing it at the disposal of the Engineer Department, or using it for garrison purposes, in rolling and weeding parades, keeping the roads and drains in order, &c., instead of wasting it upon such unproductive labour as removing shot. This question, however, can only be considered in connection with the object of imprisonment. If crime could be repressed, and a prison be made an object of aversion and dread by giving prisoners the ordinary occupation to which they had been accustomed either before they enlisted or during their service, there would be everything in favour of applying their labour to some useful purpose; but it will be in the experience of all who are practically acquainted with the subject, that no ordinary occupation can be enforced to the extent of hard labour as contemplated by the sentence of the Court, or so as to be an effective punishment. It is not the value of the labour, but the question of whether it is adapted for promoting the main object of the sentence, which should be considered, and, as far as I am enabled to form an opinion, no labour will be found so productive in prisons as that which is calculated to deter others, and the individual himself from subjecting themselves to it. The main object cannot be accomplished by amusing prisoners by such employment as will only serve to lessen the tedium of their confinement.

On a careful consideration of the subject, I am not prepared to advocate a more lenient system of prison discipline for the repression of offences in the Army, because I consider it would fail in its object, and be, in the end, the least merciful course that could be pursued. All Officers of experience agree that the sentence on military offenders should be short, and if the punishment is to have a deterring influence on others, or on the individual himself, the discipline, during periods which do not in general exceed six months, must be of a severe character. During long periods, some relaxation in favour of instruction may perhaps safely be admitted, and at all times efforts to reform must be made; but I am satisfied of the necessity of preserving under all circumstances, the general prestige of a severe punishment, either *by the length of the period of confinement*, or the *stringency of the discipline.*

Under a system calculated to inspire a certain degree of dread in the minds of soldiers, it may fairly be anticipated that many would be deterred from committing a crime, the detection and punishment of which was *certain;* and, during short periods, I should be inclined to place far more reliance on such a system in preventing the repetition of crime by the same individual, than on the effect of the better feelings and resolutions which might result from a system in which persuasion and compulsory education were the leading features. The one would operate widely on every man in the Service; the influence of the other, even under the most favourable circumstances, would be confined to the few individuals who may be subject to imprisonment, who, during an entire year, including recommittals, do not exceed 5 per cent.

It would surely be considered a great mistake to tamper with punishment, if it be designed to have any effect at all on crime, for the sake of the *possible* effects of leniency on so very small a proportion.

There appears, however, to be a tendency, at the present time, to take a very benevolent view both of crime and its consequences, and to hold exemplary punishments very cheap. Without entering into the various opinions that may prevail on such a subject, it seems reasonable to expect that, assuming simple imprisonment as the basis of discipline, it will be dreaded in proportion to the penal inflictions which may be given in addition, and cease to be so as they give place to the introduction of employment and instruction.

J. Jebb, *Colonel, Inspector-General of Military Prisons.*

EXPLANATION OF THE PLATES.

Plate I. represents the ground-plan of a Military Prison at Gosport, completed and occupied in 1850; and the construction may be considered to be based upon the several improvements deemed necessary after the experience of the previous seven years, as regards the health and discipline, the punishment of those convicted of offences, and their reform, subject to military imprisonment from one to six months, or in some cases from eighteen months to two years.

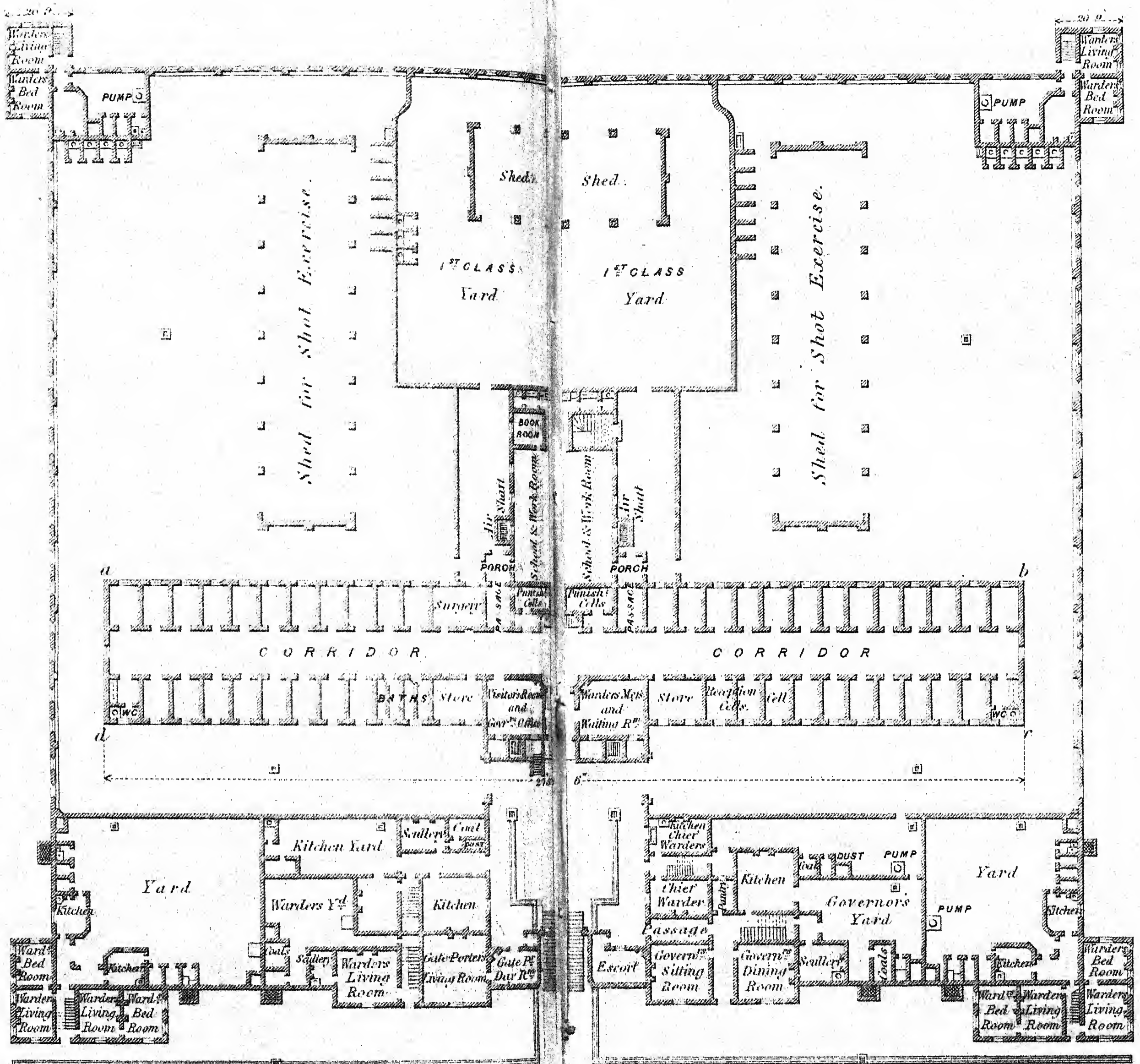
The main building, or prison, *a, b, c, d,* in Plate I., of which an elevation is given in Plate II., consists of three stories of cells. The cells are of nearly uniform size, $11' \times 7'$ (see also Plate III.), and connected by a long corridor: the latter is lighted from above and at each end.

The prison is warmed and ventilated by a furnace in the basement story and a shaft above, as explained in the longitudinal section in Plate II. Each cell has, besides, the means of receiving fresh air at the window.

Connected with the main building, and in rear of the centre, is placed the chapel with a school-room below.

The building is constructed of brick, ornamented with stone coping; jambs and sills of windows of the same material. The roof is slated.

GROUND PLAN OF THE NEW MILITARY PRISON — GOSPORT.



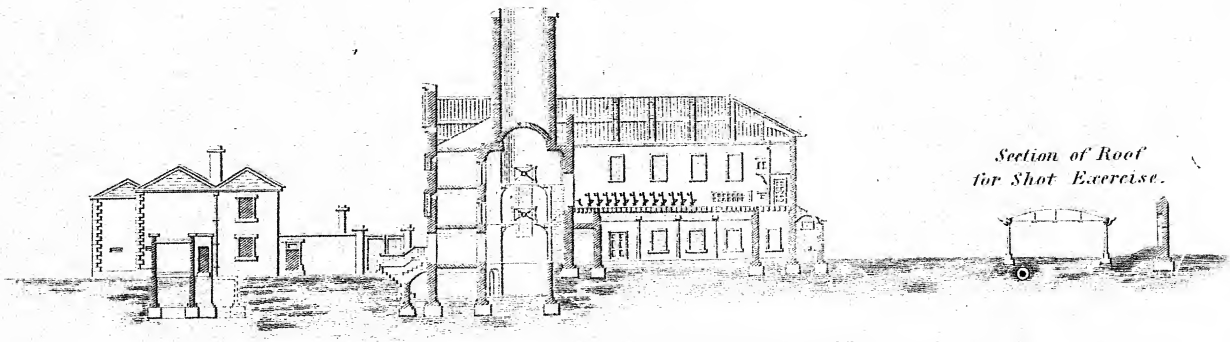
SCALE 50 FEET TO ONE INCH.

50 40 30 20 10 0 50 100 150 200 250 Feet.

W. A. Beever, Sc.

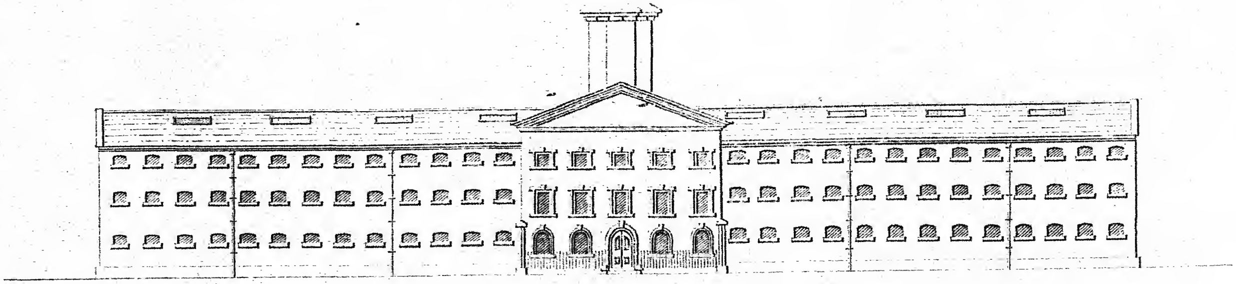
London, 1851.

FORTON NEW MILITARY PRISON — GOSPORT.



LONGITUDINAL SECTION OF CHAPEL.

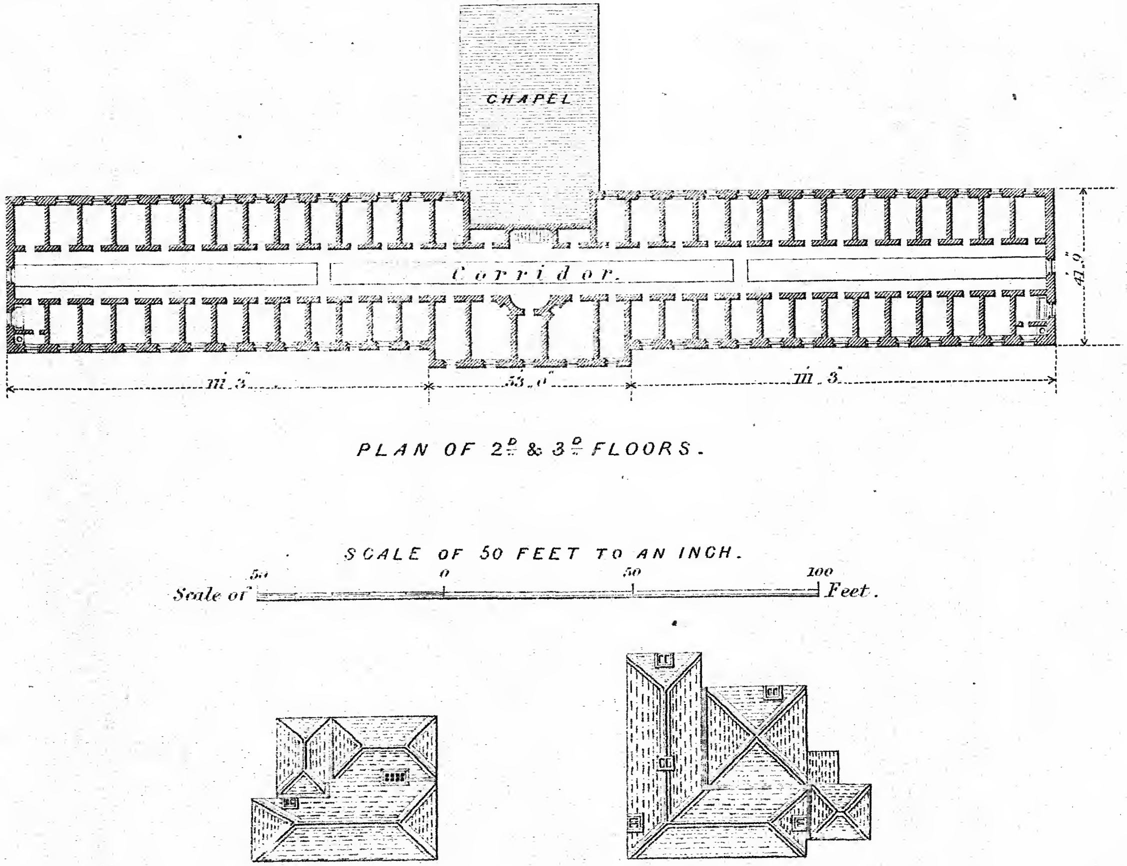
FRONT ELEVATION.



SCALE 50 FEET TO AN INCH.

W. A. Beever. Sc.

London. John Weale. 1851.



PLAN OF 2^D & 3^D FLOORS.

London. John Weale 1851.

W. A. Beever. S

The cost was £26,735 6*s.* 3*d.*, being about £178 for each cell; and the prison is built for 150 prisoners upon the 'separate system.'

The offices, stores, kitchens, and quarters for the Governor and Warders, are shown in Plate I.

Sheds for shot exercise and other punishments for the three classes are placed in the rear, on cast-iron pillars, with corrugated sheet-iron roof. See section to Plate II. —G. G. L.

PROJECTILES.*—Gunnery has been defined as the "art of using fire-arms," and in order to understand this art thoroughly in all its branches, a very considerable acquaintance with mathematics, natural philosophy, chemistry, and other sciences is required; taking the term known in a more restricted sense, it may be said to include the mechanical principles which regulate the motions of projectiles and their application to the actual purposes of practice; the remarks given in this short paper will merely illustrate this latter signification.

Leonardo da Vinci, who was born in 1452, is said to have possessed for that period a very considerable amount of knowledge relating to the dynamical laws which govern the motions of projectiles; † and N. Tartaglia an Italian in the sixteenth century, attempted to establish gunnery as a science based upon certain fixed principles, but nothing definite appears to have been determined and generally received until the time of Galileo. This celebrated philosopher whose "Dialogues on Motion" were printed in 1646, investigated the theory of projectiles and concluded that a ball fired from a gun would in its flight describe a parabolic curve, but at the same time hinting that in consequence of the resistance of the air it might under certain circumstances deviate from this curve. That a heavy mass of iron would be retarded in its flight by the resistance of the air was considered highly improbable, notwithstanding the suggestion of Galileo, but that such is actually the case was proved long afterwards by Sir I. Newton, who in his "Principia" gave the results of experiments with low velocities, and deduced from them a law that this resistance increased as the square of the velocity of the projectile; he moreover supposed that the resistance with high velocities would increase more rapidly.

The science of gunnery may be said to date from the publication of Benjamin Robins's "New Principles of Gunnery" in 1742; this distinguished philosopher carried on an extensive series of experiments with properly constructed apparatus invented by himself, and from them he clearly demonstrated that the resistance of the atmosphere affected the motion of a projectile fired from a gun to a very great extent, not only decreasing the range but causing lateral deviation; he also treated on the "Form of Gunpowder," and a number of other practical questions relating to the science of gunnery. This work of Robins was translated into German by the celebrated mathematician Euler, who added a number of original and valuable remarks, and thus brought the subject more generally before the scientific world. The experiments of Robins were afterwards more fully carried out by Dr. Hutton of the Royal Military Academy at Woolwich, who improved the apparatus used by the former, and after a long series of careful experiments, deduced a number of formulæ, from which some of the most difficult problems in gunnery may be approximately determined. Since Dr. Hutton's time experiments have been made and numerous theories connected with the

* By Major Owen, R.A., Professor of Artillery, R.M. Academy.

† See "Our Engines of War," by Captain Jervis, R.A.

science of gunnery have been investigated by many eminent men as Poissin, Probert, Didion, Magnus, Mordecai, and others.

It is not necessary to enter into the different theories respecting the "Force of Gunpowder," but it will be sufficient to state here, that when the charge of gunpowder is ignited within the bore of a gun, a highly elastic gas is suddenly disengaged, the elasticity being increased by the heat evolved in the chemical action, and an enormous force is thus exerted upon the projectile, causing it to leave the bore with a very great velocity termed its "Initial Velocity."

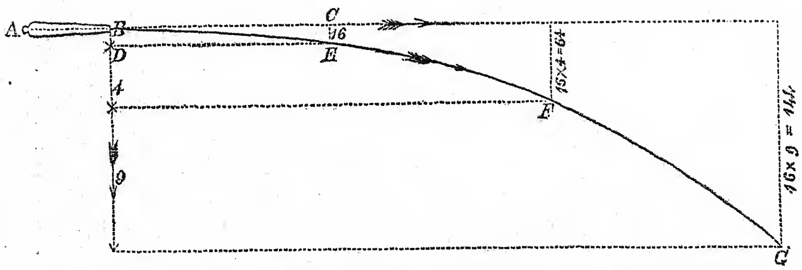
General Principles of Motion.

A projectile when discharged from a piece of ordnance is acted upon by three forces, viz. :—

1. The force of projection from the charge of gunpowder.
2. The force of gravity.
3. The resistance of the atmosphere.

Let us examine briefly the effect of each of these forces upon a shot fired horizontally from a gun, the axis of which is represented by *A B*, fig. 1.

Fig. 1.



If the projectile were acted upon by the force of projection alone, which ceases immediately it has left the bore, it would, by the first law of motion, proceed onwards in the direction *A C* with an uniform velocity, and would, in consequence, pass over equal spaces in equal times; let us suppose it to pass over the distance *B C* in one second of time. Should the shot be only subject to the action of gravity, for instance if it be allowed merely to drop from *B*, it would descend in the vertical direction *B D*, and would drop through a distance *B D* equal to about 16 feet in one second. Since, however, the projectile is acted upon by both of these forces, if the two motions be compounded, and the parallelogram *B D E C* constructed, it will, by the second law of motion, have arrived at the point *E* in one second. Also, because gravity is an accelerating force, and the spaces through which a body under its influence will fall in successive seconds are as the squares of the times, the trajectory or path of the shot will pass through the points *E F G*, and thus describe a parabolic curve as shown in the figure. The properties of this curve being known, the trajectory, time of flight, &c., of any projectile could be readily calculated if in its flight the shot was merely subject to the two above-named forces.

We must now consider the third force, viz. the resistance of the atmosphere, which so modifies the curve as to render the parabolic theory inapplicable for the purposes of calculation in gunnery, except with very low velocities of about 200 to 300 feet per second, when it would give tolerably accurate results, at least with large projectiles of great density. To projectiles moving with high velocities, there is a very considerable resistance from the atmosphere, which is generally said to vary as the square of the velocity, although Robins considered that when the velocity exceeded 1100

or 1200 feet a second, the resistance would instantly be nearly trebled; these ideas are, however, incorrect (see Boxer, Art. 234, page 106). From Dr. Hutton's experiments it appears that the resistance increases gradually up to about 1500 feet per second (with the two-inch ball), when its ratio to the velocity is as the 2·153 power of the latter, but that when the velocity exceeds this, the ratio again diminishes, for at the velocity of 1600 feet, it is as the 2·152 power, and so on till at the velocity of 2000 feet it is only as the 2·136 power (see Table, page 102. Boxer). However, in certain cases, for the sake of simplicity, the resistance of the atmosphere may be assumed to vary as the square of the velocity.

Dr. Hutton in his thirty-seventh Tract, thus explains the nature of this resistance.

"The circumstance of the variable and increasing exponent in the ratio of the resistance, is owing chiefly to the increasing degree of vacuity left behind the ball, in its flight through the air, and to the condensation of the air before it. It is well known, that air can only rush into a vacuum with a certain degree of velocity, viz. about 1200 or 1400 feet in a second of time; therefore, as the ball moves through the air, there is always left behind a kind of vacuum, either partial or complete; that as the velocity is greater, the degree of vacuity behind goes on increasing, till at length, when the ball moves as rapidly as the air can rush in and follow it, the vacuum behind the ball is complete, and so continues complete ever after, as the ball continues to move with all greater degrees of velocity. Now the resistance, which the ball suffers in its flight, is of a triple nature; one part of it being in consequence of the 'vis inertia' of the particles of air, which the ball strikes in its course; another part arises from the accumulation of the elastic air before the ball, and the third part from the continued pressure of the air on the fore part of the ball, when the velocity of this is such as to leave a vacuum behind it in its flight, either wholly or in part; for, while the ball is at rest, it is manifest that this pressure of the whole atmosphere is the same or equal on all sides of the ball; but, as soon as the ball begins to move, it is also manifest that the pressure behind will be less than the constant degree of pressure in front, and the difference must be the greater as the motion of the ball is the more rapid, being, in fact, proportional nearly as the velocity of the ball as compared with that of air rushing into a complete vacuum, that is, while the former is not greater than the latter; for, as soon as the motion of the ball becomes equal to that of the air, and always when greater, then the ball has to sustain the whole pressure of the atmosphere on its fore part, without having any aid from a counter-pressure behind.

"Thus then we see that the resistance against the ball is two-fold (besides that arising from the unknown degree of compression before the ball), the one arising from percussion, by the ball striking and displacing the particles of air in its path, and which increases continually in the duplicate proportion of the ball's velocity; and the other from the weight of the atmosphere, increasing with that velocity, to which, being of the nature of pressure, it is proportional; but arriving at its maximum when that is equal to or exceeds the velocity of air into a vacuum, after which it is a constant quantity for all greater degrees of velocity. These circumstances then very well show the reason why the experimental resistance proceeds in a ratio increasing gradually more and more above the square of the velocity, till this exceeds 1200 or 1400 feet, the motion of air into a vacuum, and then rather decreases again. So that it appears that the whole estimatable resistance consists of two parts; of which the one part is proportional to the square of the velocity, and the other is simply as the velocity only."

Hutton's formula in two terms for this resistance is

$$mv^2 + nv = r,$$

m and n being general coefficients determined by experiment.

In order to ascertain approximately the effect of the resistance of the air upon projectiles, their probable trajectories, the relative effects produced by different charges and many other important questions in gunnery, it is necessary to determine as accurately as possible the "Initial Velocities" of projectiles. For this purpose the Ballistic Pendulum and the Gun Pendulum have been employed until within the last few years, during which an Electro Ballistic Apparatus has been invented, and is now very generally used. The invention of the Ballistic Pendulum by Robins was a most important discovery enabling him to make reliable experiments, and thus establish the theory of gunnery, which had hitherto depended upon no acknowledged principles as a science. The principle of this instrument may be thus explained:

Ballistic Pendulum.

Ballistic Pendulum.—If a shot be fired from a gun into a large block of wood, or other material, placed at a short distance from the piece, and suspended so that it can vibrate freely; it is known by the 3rd law of motion (action and re-action) that the momentum gained by the latter is lost by the ball; and therefore that the momentum of the ball before impact is equal to that of the block with the ball in it after impact. Now if the velocity of the block with the ball in it can be ascertained, the weight of the two being known, their momentum after impact is also known, and from what has before been said, this momentum is equal to that of the ball before impact; the velocity of the ball is therefore easily found. Thus

If w = weight of ball.
v = velocity of ditto before impact.
W = weight of block.
V = velocity of block, with ball after impact.

$$w \, . \, v = (W + w) \, V.$$

$$v = \frac{(W + w) \, V}{w} .$$

Example.—If a 32 lb. shot be fired into a block weighing 8000 lbs., and the velocity after impact is 4 feet per second, what will be the velocity of the ball before striking?

$$v = \frac{(8000 + 32) \, 4}{32}$$

$$= 1004 \text{ feet per second.}$$

The "Initial Velocity" of the block can be ascertained from the arc of vibration; for the velocity lost by its centre of oscillation in ascending the curve is the same as that gained in descending, which latter is equal to the velocity it would acquire in falling through the same vertical distance; this height is equal to the versed sine of the angle of semi-vibration multiplied by the distance of the centre of oscillation from the axis of suspension.

When the shot strikes the centre of percussion of the block, the velocity of the ball may be computed from the following formula:—

Let w = weight of the ball
V = velocity of ditto.
O = distance of the centre of percussion or oscillation from the axis of suspension.
C = weight of the pendulum.
G = distance of centre of gravity from the axis of suspension.
a = angle of semi-vibration.
g = accelerating effect of gravity.

$$V = 2 \sin. \tfrac{1}{2} . a . \frac{(C \, G + w \, O) \sqrt{g . O}}{w . \, O.}$$

This formula will be sufficiently accurate for short distances, but should the block be placed at a considerable distance from the gun, and the shot strike far from the

centre of percussion another formula must be used; this latter formula, as well as that for finding the velocity lost by the ball before reaching the block, are given in Boxer's Treatise on Artillery,* where will also be found a full explanation of them. The ballistic pendulum used by Robins consisted of 3 poles or legs joined at the top, but spreading out at the bottom so as to form a frame for the block; the latter was of iron covered with wood, and suspended from the middle of a horizontal cross piece fitting into sockets attached to two of the legs near their tops, and in such a manner that the block could vibrate as freely as possible. In order to ascertain the arc of vibration, after the block had been struck by the shot, a ribbon was attached to the lower part of the block, and passed through two small steel edges capable of being compressed to the extent required, fixed into a horizontal brace attached to the two legs below the block. The length of ribbon drawn out by the block thus measured the arc of vibration.

Dr. Hutton made several improvements in Robins's pendulum, replacing the sockets by others of superior construction, which diminished the friction, and substituting for the ribbon a graduated arc having a groove filled with soft composition of wax and soap, so that a stylette attached to the block traced the extent of the arc of vibration in this composition. The Ballistic Pendula since used in France and America were very great improvements on that of Hutton, but a description† of them would occupy too much space for a short article; their blocks were made with moveable cores filled with clay or sand, so that the shot would remain in the block, and not be liable to rebound on striking, but could be removed after each round. In order that the pendulum should not be affected by the blast from the discharge, it is usually placed at a distance of about 50 feet from the muzzle of the gun, and to insure this more effectually, a wooden screen should be placed a few feet (about 17) from the gun, having a hole 12 inches in diameter for the shot to pass through.

endulum.

The general principle upon which the Initial Velocity of a shot can be obtained by means of the Gun Pendulum is as follows. When a shot is fired from a gun the force exerted by the ignited powder acting in one direction upon the shot but in the opposite direction upon the gun,‡ the momentum of the shot will be equal to that of the gun; if therefore by suspending the piece in a frame, provided with a graduated arc, in such a manner that it can vibrate freely, the initial velocity of recoil of the gun can be observed as explained with the block of the ballistic pendulum, and the respective weights of the gun and shot being known, the velocity of the latter can be readily ascertained.

This method of finding the velocity of a shot is not however strictly correct, and the velocity found thus would be too high for the following reasons. First, the motion of the powder and bag in the direction of the shot must be considered; secondly, a portion of gas escaping by windage, a less amount of force will act upon the shot than upon the gun from this cause; thirdly, the force will act for a longer time upon the gun than on the shot. The gun will therefore have a greater momentum than the shot; the formula to be employed when these circumstances are taken into account is given in Boxer's Treatise on Artillery.

ng
ue.

With low velocities (less than 100 ft. per second) the shot will generally rebound from the block of the Ballistic Pendulum, and on account of the elasticity of the shot and block the results would be very inaccurate; in order to ascertain the resistance

* Also in "Hutton's Tracts," "Report of Experiments on Gunpowder," by Captain Mordecai, &c.

† A detailed description will be found in Boxer's "Treatise on Artillery;" Mordecai's "Report of Experiments on Gunpowder," &c.

The elastic gas exerts an equal pressure in every direction.

to balls moving with these low velocities Robins invented an ingenious instrument called a whirling machine, which is described in his "New Principles of Gunnery," in Hutton's Tracts," &c.

Electro Ballistic Apparatus.

The Electro-Ballistic Apparatus* of Navez is too complicated to describe, especially without the aid of accurate drawings, but its general arrangement, and the principle upon which the velocity of a shot can be obtained by it, may be briefly explained as follows. Two screens are placed in front of the gun, one within a few feet, and the other at some distance from the first, depending upon the results required; the gun is accurately laid so that the shot fired from it may pass through both screens, in doing which it cuts a copper wire in each. The apparatus consisting of a pendulum with a a powerful magnet, a galvanic battery, &c., is placed at some distance from the gun so as not to be affected by the discharge, and it is connected with the screens by means of copper wires. When the wire of the first screen is cut, the pendulum commences to vibrate, but when the wire in the second is cut, an index hand attached to the pendulum is suddenly clamped, and thus registers the length of the arc of vibration, which shows the time the shot takes to pass from one screen to the other with the very greatest accuracy. This instrument has many advantages over the Ballistic Pendulum, it is not so cumbrous, observations can be made with greater rapidity and accuracy, it can be employed at high angles of elevation, or where it is required to ascertain the velocity of a shot at a considerable distance from the gun, &c.

Dr. Hutton deduces the following practical conclusions (in his 37th tract) from experiments carried on by himself at Woolwich :—

Velocity.

1. "It appears that the (initial) velocity of a ball increases with the increase of charge only to a certain point, which is peculiar to each gun, when it is greatest; and that, by further increasing the charge, the velocity gradually diminishes till the bore is quite full of powder. That this charge for the greatest velocity is greater as the gun is longer, but yet not greater in so high a proportion as the length of the gun is; so that the part of the bore filled with powder bears a less proportion to the whole bore in long guns, than it does in shorter ones; the part which is filled being indeed nearly in the inverse ratio of the square root of the empty part."

2. "It appears that the (initial) velocity with equal charges, always increases as the gun is longer; though the increase in velocity is but very small in comparison to the increase in length, the velocities being in a ratio somewhat less than that of the square roots of the length of the bore, but greater than that of the cubic roots of the same, and is, indeed, nearly in the middle ratio between the two."

3. "It appears from the Table of Ranges, that the range increases in a much lower ratio than the velocity, the gun and elevation being the same; and when this is compared with the proportion of the velocity and length of gun, in the last paragraph, it is evident that we gain extremely little in the range by a great increase in the length of the gun, with the same charge of powder. In fact, the range is nearly as the fifth root of the length of the bore, which is so small an increase, as to amount only to about one-seventh part more range for a double length of gun. From the same Table, it also appears, that the time of the ball's flight is nearly as the range, the gun and elevation being the same."

4. "It has been found by these experiments, that no difference is caused in the velocity or range by varying the weight of the gun, nor by the use of wads, nor by different degrees of ramming, nor by firing the charge of powder in different parts of

* The idea of determining the velocities of projectiles by means of electricity was first suggested many years ago by Professor Wheatstone, who invented an instrument called the electro-magnetic-chronoscope for this purpose.

it; but that a very great difference in the velocity arises from a small difference in the windage."

The velocities generated by the action of different charges of powder in the same gun upon balls of equal densities, are nearly as the square roots of these charges; or

$$v : v' :: \sqrt{c} : \sqrt{c'}.$$

The velocities generated by the same charge of powder from the same gun upon balls of different densities, will be inversely as the square roots of the weights; or

$$v : v' :: \sqrt{w'} : \sqrt{w}.$$

The velocities generated by different charges of powder upon balls of different densities, will be nearly in the ratio of the square roots of the charges, divided by the square roots of the weights of the balls (Boxer, pp. 50, 51); or

$$v : v' :: \sqrt{\frac{c}{w}} : \sqrt{\frac{c'}{w'}}$$

In the above

v and v' being the initial velocities,
c = charge with v,
c' = do. v',
w = weight of ball with v,
w' = do. do. v'.

The empirical formula generally used in our service for ascertaining the initial velocity of a projectile, is as follows:—

$$V = 1600\sqrt{\frac{ac}{w}}, \quad \ldots \ldots \quad (1).$$

when V = initial velocity,
a = a coefficient, the value of which depends upon windage,
c = the charge (in lbs.),
w = the weight of ball (in lbs.),

The values of a found by experiment are,

for windage of	·233	3·2
,,	·2	3·4
,,	·175	3·6
,,	·125	4·4
,,	·09	5·

Should there be no windage, a would equal 6·66.

Recoil and Strain.

The elastic gas generated by the ignition of gunpowder, exerts an equal pressure in every direction; consequently, when a gun is discharged, a force is impressed upon the bottom of the bore of the gun in the direction of the axis equal in amount,* to that which acts upon the projectile. The momentum of the gun and carriage, is therefore equal to that of the projectile, both being acted upon by equal forces, and the velocity of recoil of the former may be found as follows:—

If G = weight of gun,
C = do. carriage,
w = do. shot,
v = initial velocity of shot,
V = do. gun and carriage,

$$wv = (G + C)\,V$$

$$V = \frac{wv}{G + C}, \quad \ldots \ldots \quad (2).$$

v may be determined from the formula for finding the initial velocity of shot.

* Not strictly correct, as explained when describing the principle of the gun pendulum.

Or should the velocity of recoil of the gun alone be required;

If V' = initial velocity of recoil of gun.

$$V' = \frac{wv}{G} \quad \ldots \ldots \ldots \ldots \quad (3).$$

The above simple formulæ are of great practical utility in comparing the velocities obtained from ordnance with different charges and projectiles, the destructive effects exerted upon the carriages, &c.

If two guns have bores of the same calibre, but the weight of one gun is double that of the other, their respective velocities of recoil, and also the strains exerted upon their carriages, when fired with equal charges and similar projectiles, will be inversely as their weights.

If v = velocity of shot,
w = weight of do..
W = weight of the 1st gun,
W' = do. 2nd ,,
V = velocity of the 1st ,,
V' = do. 2nd ,,

The momentum of each gun will be equal to vw.

$$\text{but } V = \frac{vw}{W},$$

$$\text{and } V' = \frac{vw}{W'},$$

or the velocities of recoil are inversely as the weights.

The work done by the guns in their recoil, and consequently the strains upon the carriages will be, as

$$WV^2 : W'V'^2,$$

or, by substituting the values of V and V', as

$$\frac{v^2w^2}{W} : \frac{v^2w^2}{W'},$$

or the strains are inversely as the weights.

In Sir H. Douglas' Naval Gunnery, it is stated, "That by increasing the charge beyond one-third of the weight of the ball, the recoil is increased in a much higher ratio than the initial velocity of the ball. It may be added, that for every purpose on service, even for that of breaching, the advantage gained by using a charge greater than one-third of the weight of the shot is unimportant, and does not compensate for the inconvenient recoil, or the destructive strain on the gun and carriage."

The above refers to smooth-bored ordnance, for with rifled cannon the charges are much less, usually one-sixth or one-eighth of the weight of the projectile; it must, however, be remembered, that these small charges have a much greater proportional effect, from the fact of there being little or no windage in a rifled cannon, and from the comparatively great weight of the projectiles (elongated) used with them.

Resistance and Retardation.

The "resistance" which a projectile meets with in moving through the atmosphere depends chiefly upon its velocity, the magnitude of the surface it presents to the resistance, and its peculiar form.* In the case of ordinary spherical projectiles, supposing the resistance to vary as the square of the diameter, if d = the diameter of a ball, and v = its velocity, the resistance opposed to its motion will be as

$$d^2v^2.$$

The velocity it loses in consequence of this resistance, or its "retardation," will,

* This subject is treated in a more general manner in Boxer's Treatise, p 107.

however, depend also upon its weight, being in fact inversely as the weight, and the weight is proportional to the cube of the diameter, so that the retardation of the ball will be as

$$\frac{d^2 v^2}{d^3}.$$

If two shot of different diameters are fired under similar circumstances, that is, supposing the angles of elevation of the guns from which they are respectively fired are the same, the initial velocities equal, and the densities of the shot alike (for instance, should they be two cast-iron solid shots), it appears from what has just been said, that the shot of the largest diameter will range to a greater distance than the other, the resistance to each being as d^2, whereas the retardation is inversely as d^3; consequently, for equal ranges, the elevation of the piece from which the larger shot is fired may be reduced, and the chance of its striking the object fired at will therefore be greater than that of the smaller ball, the trajectory of the latter being more curved.

If a shell and solid shot of equal diameters, but the densities of which are of course different, be fired consecutively from a gun, at the same elevation, and with equal charges, their initial velocities will be inversely as the square roots of their respective weights, the velocity of the shell being therefore the greatest; the shell will, however, in consequence of its inferior weight, be more retarded by the resistance of the atmosphere than the shot, so that, although at short ranges, when firing shell, the elevation of the gun would be rather less than when firing solid shot, still at long ranges the elevation would be about the same, whether shot or shell were fired, or would be even less for the shot. For instance, it was found by actual practice, in the Woolwich marshes, that at a range of 1400 yards, the 32-pr. gun of 56 cwt. required about the same elevation whether shot or shell were fired, but at 1000 yards the shell required about one fourth less than the shot.* In the Tables of Ranges given in the Hand-Book for Field Service, the ranges of the shell for the same gun are greater than those of the shot up to 5° of elevation, when they are both equal, viz. 1910 yards, after which the ranges of the shot exceed slightly those of the shell.

If balls of equal diameters but of different weights or densities, as solid shot and shell, are fired from the same gun with charges bearing the same proportion to their respective weights, their initial velocities will be equal,† as will appear from the formula for initial velocity. The ranges at "point blank" or small elevations will not differ to any great extent, but at angles of elevation giving long ranges, the times of flight for which will be considerable, the retardation of the denser ball will be much less than that of the lighter, and consequently it will range to a greater distance.

In order to show clearly the extent to which the range of an ordinary projectile is decreased by the resistance it meets with from the atmosphere, the following example is given.

Example.—If a solid shot were fired in vacuo from a 32-pr. gun of 56 cwt. at 2° of elevation, and with the service charge, to what distance would it range?

From the formula at page 158, we find the initial velocity of the shot to be 1600 feet per second.

The equation for the range being

$$R = \frac{2\, V^2 \sin a \cos a}{g},$$

and as $2 \sin a \cos a = \sin 2a$,

---

* The service charge of 10 lbs. used with both shot and shell,

† Any difference would arise from the charges not being of equal length.

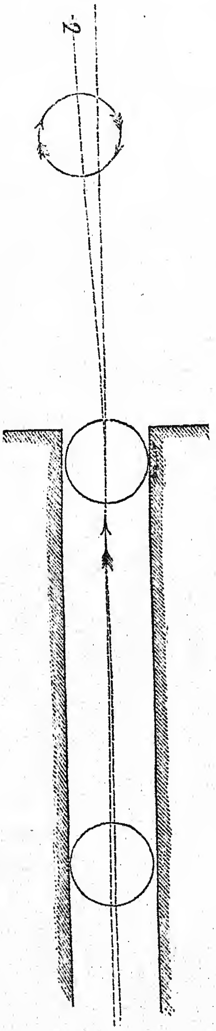
$$R = \frac{V^2 \sin 2\alpha}{g}$$
$$= \frac{2560000 \times \cdot 069}{32}$$
$$= 5520 \text{ ft. or } 1840 \text{ yds.}$$

In the air the range would be about 1100 yards, or less than two-thirds of the range in vacuo.

Final or remaining and terminal velocity.

These two terms are defined below, but it would occupy too much space to go into the formula connected with them, which may however be found if required in Boxer's Treatise, Hutton's Tracts, &c.

Fig. 2.



The final or remaining velocity of a projectile is its velocity at the end of any given range.

If a body be allowed to fall in the atmosphere, there is a certain limit to the velocity it will acquire, and this will be attained when the resistance of the air has become equal to the accelerating force of gravity; the motion of the body will then be uniform, and is called its Terminal Velocity.

[As the subject of PENETRATION is treated in a separate article, it is here omitted.]

Deviations of projectiles from smooth-bored ordnance.

Very great irregularities occur in the paths described by projectiles fired from smooth-bored ordnance. It is a fact, well known to all practical artillerists, that if a number of solid shot (or any other projectiles) be fired from the same gun, with equal charges and elevations, and with gunpowder of the same quality, the gun carriage resting on a platform, and the piece being laid with the greatest care before each round, very few of the shot will range to the same distance; and, moreover, the greater part will be found to deflect considerably (unless the range be very short) to the right or left of the line in which the gun is pointed.

The principal causes for these deviations are,*

1. Windage;
2. The imperfect form and roughness of surface of shot;
3. Eccentricity of projectile arising from a want of homogeneity.

Windage causes irregularity in the flight of a projectile from the fact of the elastic gas acting in the first instance on the upper portion of the projectile, and driving it against the bottom of the bore; the shot re-acts at the same time that it is impelled forwards by the charge, and strikes the upper surface of the bore some distance down, and so on, by a succession of rebounds, until it leaves the bore in an accidental direc-

* Wind affects projectiles from rifled bores, and is not therefore mentioned here.

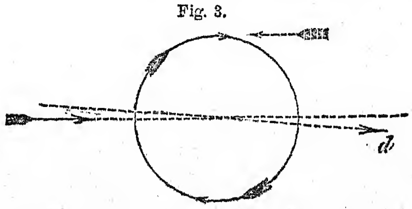
tion, and with a rotatory motion, depending chiefly on the position of the last impact against the bore.

Thus, should the last impact of a (concentric) shot when fired from a gun be upon the right-hand side of the bore, as represented in fig. 2, the shot will have a tendency to deflect to the left in the direction *b*, while at the same time a rotation will be given to it in the direction indicated by the arrows.

Shot cannot be cast with perfectly smooth surfaces ; consequently, a certain amount of friction is said to arise between these surfaces and the atmosphere.*

It was asserted by Robins, "That almost all bullets receive a whirling motion by rubbing against the sides of the pieces they are discharged from ; and that this whirling motion of the bullet occasions it to strike the air oblique to the track of the bullet, and consequently perpetually deflects it from its course." The manner in which the ball is deflected, according to Robins, may be thus explained.—As the air in front of the ball will in the above case be greatly condensed, while almost a vacuum will be formed behind the ball, a great resistance will be offered by the friction of the air in front, which will not be counterbalanced by a corresponding resistance behind, and therefore the ball will have a tendency to deflect in the opposite direction to that given by striking the right side of the bore. This is shown in fig. 3, the dotted arrow representing the resistance caused by the friction of the air to

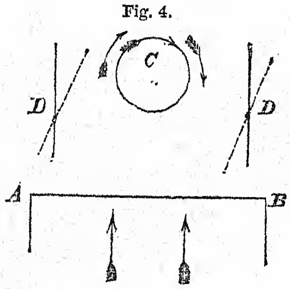
Fig. 3.



the rotation, and which, not being balanced by a corresponding resistance to the opposite hemisphere, will cause the ball to deflect in the direction *d*.

Professor Magnus, of Berlin, made a number of careful experiments some few years ago, to ascertain the causes for the deviations of projectiles, and as they appear to afford the most probable explanations for the different results observed in practice, it is considered necessary to give some account of them here; those relating to spherical projectiles only will be described at present.

Fig. 4.



The first object was to determine the relative amount of atmospheric pressure exerted on different parts of the projectile, when the latter has imparted to it a motion of translation as well as a motion of rotation. It was assumed that the relative pressures upon the projectile are the same, whether it is made to move with a certain velocity through the air, or whether a current of air is impelled with the same velocity against the projectile.

Observations being more easily made on a cylinder than on a sphere, a brass cylinder (see fig. 4) about $1\frac{1}{2}$ inch in diameter and 4 inches high was used to represent the pro-

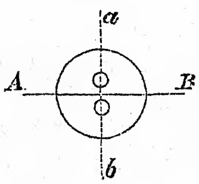
* The greater part of the following remarks are extracted from some printed lectures prepared by Major Owen, R.A., for the R. M. Academy.

jectile, and it was arranged so that it could be made to rotate rapidly on a concentric or eccentric vertical axis. The current of air was produced by means of a rotating fan, the direction in which it was driven being perpendicular to the axis of the cylinder; the nozzle AB which delivered the stream was five inches wide, so that the cylinder might be within the current whatever the position of its axis; the depth of the nozzle was three-quarters of an inch. Two light moveable vanes (DD) were placed on each side of the cylinder, so that their pivots were equidistant from the mouth of the blower and from a vertical plane passing through the centre of the current and the axis of the cylinder.

If the cylinder is at rest and the current of air impelled against it, the pressures will manifestly be equal on both sides of the axis, and the vanes are found to place themselves parallel with the current. But when the cylinder is made to rotate from left to right, as indicated by the arrow in the circumference of C, fig. 4, the portion of air in contact with it (dotted arrows round, see fig. 4) is also made to rotate in the same direction. The cylinder being made to rotate, and the blower being also applied, it is found that the vane on the left side of the cylinder, when the current of air from the blower and the rotating current follow the same direction, approaches the cylinder, but the vane on the other side where the two currents move in opposite directions is found to recede from the cylinder. It would appear from this that on the left side there is a diminished pressure, and on the right side an increased one, compared with the pressures on the cylinder when at rest. In order to obtain the most distinct effects, the velocity of the air produced by rotation must be nearly as high as that of the current of air from the blower.

It was shown by M. F. Savart that if two jets of liquid, flowing with the same velocity from circular orifices of the same diameter, meet each other, when their axes are in the same straight line, the two together move laterally and in a plane perpendicular to the jets. This may be illustrated in the case of gases by the ordinary fish-tail burner, the flame from which is in a plane at right angles to that passing through the two perforations from which the flame issues; thus in fig. 5, AB represents the plane of the flame, and ab that passing through the perforations. Also in the experiment with the cylinder, on the right side where the current of air from the blower moves in an opposite direction to the air rotating with the projectile, when they thus meet they move laterally, an increased pressure being therefore exerted on the vane forcing it outwards, and on the cylinder; whereas on the opposite side, in consequence of the two currents of air moving together, the pressure is decreased, and the vane approaches the cylinder.

Fig. 5.

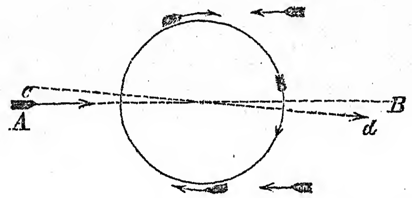


In order to prove that the difference of pressure upon the opposite hemispheres of the ball is sufficient to cause it to deviate, Professor Magnus devised the following experiment:—"A light beam of wood, about four feet in length, is suspended from its centre by a thin wire, so as to form a sort of torsion balance; from one end of this beam a brass rod descends carrying a brass ring, within which a light brass cylinder (similar to that described above), turns very freely on an axis, in the same manner as a common terrestrial globe turns within its brazen meridian. At the other end of the beam a counterpoise is adjusted. The blower before cited is placed below the beam, so that it may be made to turn horizontally about a point nearly coincident with the prolongation of the suspending wire, while the mouth is about two inches from the cylinder. The plane of the ring being made perpendicular to the direction of the blast, the cylinder is now made to rotate rapidly from right to left, or *vice versâ*, by means of a thread wound round its axis, in the same manner as a humming top is

spun. While this is in a state of rotation the blower is put into action. The beam then with the cylinder revolves, and may be made to describe a large portion of a circle, the direction of its orbit depending on the direction which is given to the rotation of the cylinder on its axis." *

Let these principles be applied to the case of ordinary spherical projectiles fired from guns. If a ball leaves the bore rotating on a vertical axis, the fore part of the ball moving from left to right, supposing the observer to be behind the piece, it follows from what has been previously said that there will be a diminished pressure on the right side, and an increased one on the left side of the ball, which will therefore deviate to the right: this is shown in fig. 6, in which $A\ B$ represents the direction in which the ball is impelled, $c\,d$ that of the deviation, and the small arrows outside the

Fig. 6.



ball, the directions of the two currents of air on both sides. In like manner, if the fore part of the ball turns from above downwards, the increased pressure will be above and the decreased below, and the range would therefore be diminished. In one case alone will there be no deviation from the causes described, and that is when the axis of rotation of the ball is tangential to its trajectory.

It has been already explained, that the velocity of the air rotating with the ball must be nearly as high as that of the opposing current, in order that the pressure on one hemisphere caused by the meeting of the two may have sufficient power to produce very evident deviations; this will in some measure explain the fact, that the lateral deviation is found in practice to increase in a higher ratio than the distance, for the velocity of translation decreases most probably more rapidly than that of rotation, and therefore the velocities of the two separate currents will become more nearly equal.†

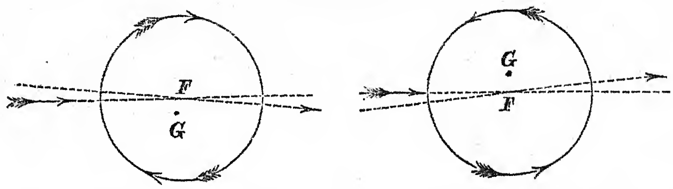
From the above explanations, either of Robins or Magnus, it appears that a ball leaving the bore of a gun rotating on any axis, but on one parallel to the axis of the bore, will deviate according to the direction of the rotation; and they will account for the results of experiments with eccentric projectiles. Should the centre of gravity of a shot not coincide with the centre of the figure, the shot is termed eccentric, and is found to deviate according to the position of the centre of gravity when the ball is placed in the bore of the gun. Should the line joining the centre of gravity and the centre of the figure of a projectile be not parallel to the axis of the bore, the charge of powder will act upon a larger surface on one side of the centre of gravity than on the other, so that there will be a rotation from the lightest to the heaviest side. If fig. 7 represents an eccentric shot, the centre of gravity (G) of which is below its centre of figure F, the powder, acting on a larger surface above G than below, will give it a rotation as indicated by the arrows, and from what has been previously said, its deviation will be to the side upon which the centre of gravity lies. This is the case

* Journal of U. S. Institution, vol. ii. p. 493.

† It appears that if a shot rotates on any axis when leaving the bore of a gun, it will deflect in the same direction, according either to Robins or Magnus.

in practice, for it is found by experiment that if a shot be placed in a gun, so that its centre of gravity is to the right of the vertical plane, passing through the axis of the bore, the shot will deviate towards the right, and *vice versâ*; also if the centre of

Fig. 7. Eccentric shot. Fig. 8.



gravity be upwards the range will be increased, and if downwards diminished. Figs. 7 and 8 will illustrate these remarks.

It is found in practice that shot deviate in a curved line, either right or left, the curve rapidly increasing towards the end of the range. This most probably occurs from the velocity of rotation decreasing but slightly, compared to the velocity of translation of the shot as before explained; or, if a strong wind is blowing steadily across the range during the whole time of flight, this deflecting cause being therefore constant, while the velocity of the shot diminishes, the curve will manifestly increase with the range. The trajectory is therefore a curve of double curvature, its projection on either a horizontal or vertical plane being a curved line.

Rifling. By a successful introduction of the rifle system in the construction of ordnance and projectiles, the chief causes of deviation are very greatly diminished. The object of rifling the bore of a piece of ordnance (or of a musket barrel), is to give the projectile a rotary motion on an axis parallel to that of the bore, or coincident with the "line of fire." By giving this rotation to the shot, the friction or the pressure of the air will be equally distributed round it, thus obviating the chief cause of deflection, and securing greatly increased accuracy.

In order to give the required rotation, two or more grooves are cut spirally down the length of the bore, and the projectile must have projections on its surface to fit into those grooves, as in the Cavalli, Warhendorff, and French rifled cannon, or else a portion or all of it must be composed of soft material, so that this latter may, by the force of explosion, be expanded as in the Minié rifle, or compressed, as in the Armstrong gun, into the grooves, the projectile being therefore constrained to follow their direction while passing through the bore. There are other plans of effecting this, as the Lancaster, Whitworth, &c., but they will be found on examination to be modifications of one or other of the above three.

The three most important considerations in the application of the "rifle principle" to fire-arms are—

1. The form and diameter of projectile.
2. The inclination of the grooves.
3. The charge of powder.

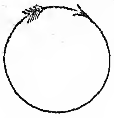
The rifled muskets first introduced which had two grooves were fired with a belted spherical ball, but the advantages of elongated projectiles over spherical bullets became so manifest that the latter are no longer used with rifled pieces. Elongated projectiles cannot be used with smooth-bored pieces, for after ranging to a short distance, from their tendency to rotate round their shorter axes, they turn over in their flight, and are therefore useless. The rotation given to an elongated projectile, round its longer

axis, in passing through the bore of a rifled piece, ensures its proceeding in the desired direction with but little deviation.

In 1747, Robins suggested an elongated bullet of an egg-like form :—"For," he says, "if such a bullet hath its shorter axis made to fit the piece, and it be placed in the barrel, with its smaller end downwards, then it will acquire, by the rifles, a rotation round its longer axis; and its centre of gravity lying nearer to its fore part than its hinder part, its longer axis will be constantly forced by the resistance of the air into the line of its flight; as we see, that by the same means, arrows constantly lie in the line of their direction, however that line be incurvated." Before explaining the advantages derived from the use of elongated projectiles, it is necessary to consider some of the peculiar circumstances connected with their flight in the atmosphere.

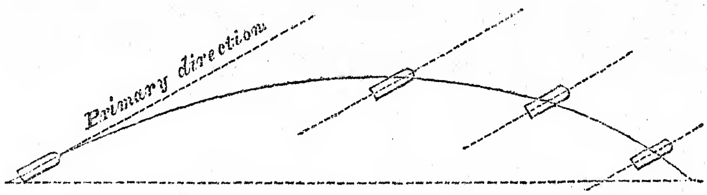
All elongated projectiles fired from rifled guns deviate laterally, and the deviations of projectiles of ordinary form from the same piece occur on the same side of the production of the axis of the bore. With almost every rifled gun hitherto constructed, this lateral deviation of its projectile, or, as the French term it, "derivation," is to the right arising from the direction of the grooves, which are almost invariably made so as to give the projectile what is called a "right-handed" rotation; that is to say, the upper part of the projectile turns from left to right, with reference to an observer placed behind the piece. (Fig. 9.)

Fig. 9.



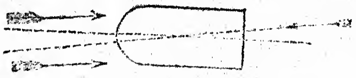
If the axis of the projectile remained tangential to the trajectory during the whole time of flight, the resistance of the air would be equally distributed round it, and no lateral deviation would take place. It is however a well ascertained fact, that the axis of the projectile remains nearly parallel to its primary direction during the whole time of its flight, as represented in fig. 10, and moreover that it also makes

Fig. 10.



a certain angle with the vertical plane passing through the production of the axis of the bore; in consequence of this latter position of the axis of the projectile, lateral deviation must occur from the fact of the resistance of the air being greater on one side of the axis than on the other. (Fig. 11.)

Fig. 11.



Causes of deviation.

In order to discover the cause of "deviation" in elongated projectiles, Dr. Magnus endeavoured by direct experiment to seek a more positive knowledge, than any hitherto obtained, as to the direction of the axis of the elongated projectile during its flight. The following experiment was made at his suggestion by a Royal Commission at Berlin. Several elongated projectiles were fired with a charge and consequent velocity so low,

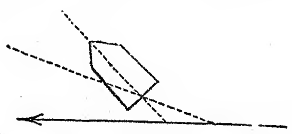
that an observer could follow them with the eye, and even note with accuracy the position of their axes; the following were the results obtained: —*

1. "All the observers stationed at intervals along the range unanimously agreed, that the axis of the projectile during the whole time of flight remained nearly tangential to the trajectory, but nevertheless that in the descending branch, it was easily seen that the point of the projectile was a little higher than could have been the case had the axis remained accurately tangential to the trajectory.

2. "It was also admitted by all, that, as much from the motion of the projectiles as from the furrows made in grazing the ground, in all the rounds fired, the point of the shot at the instant of touching the ground had a deviation to the right, as shown in fig. 12.

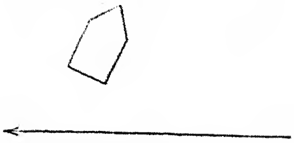
3. "When a projectile strikes the ground in such a direction (as mentioned above),

Fig. 12.



Prolongation of Axis of Bore.

Fig. 13.



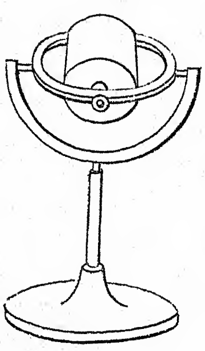
Prolongation of Axis of Bore.

there may take place during the penetration a turning over of the shot, so that the posterior or base becomes foremost, and that is exactly what took place in most of the rounds fired in this experiment; for those projectiles which buried themselves in the ground were found, with reference to the plane of fire, in a position similar to that shown in fig. 13."

Experiment with the gyroscope.

That the axis of an elongated projectile makes an angle with the vertical plane passing through the production of the axis of the bore, may be proved by experiment with the gyroscope. The gyroscope for this purpose should have a small elongated projectile substituted for the disc used for ordinary experiments, and the projectile must be made with the greatest care, so that its centre of gravity coincides exactly with that of the two rings within which it is placed; the rings are so arranged that one can turn round a vertical axis and the other round a horizontal axis, the projectile within being therefore free to turn in any direction. A cylindrical portion of metal extends beyond the base of the projectile, in prolongation of its longer axis, round which the string is wound to give the required rotation to the shot. (Fig. 14.)

Fig. 14.



If the projectile be made to rotate rapidly, and a pressure is exerted underneath its point, so as to represent the pressure of the atmosphere, which, in consequence of the axis maintaining nearly its primary direction, is greater below than above the point, and in front than behind the centre of gravity, this pressure instead of raising the point of the projectile will cause it to move laterally according to the direction of the rotation; if the rotation be "right handed" the point of the projectile will incline to the right, and if "left handed" to the left. Should the pressure be greater behind the centre of gravity than in front of it, then the point of the projectile

* Occasional papers, R. A. Institution, vol. i., p. 434.

would with a "right handed" rotation move to the left, and with a "left handed" to the right.

Advantages of elongated projectiles.

Elongated projectiles cannot, as before observed, be fired from smooth-bored pieces, but require a certain velocity of rotation about their longer axes, which is communicated to them in passing through the bore of a rifled gun, and which preserves them during their flight from turning over in consequence of their tendency to rotate about their shorter axes. Fired from rifled pieces, elongated projectiles attain much longer ranges, combined with far greater accuracy than spherical shot of equal diameter, fired from the same pieces at the same angles of elevation, and with equal initial velocities. The elongated projectiles from their greater weight are less retarded, maintain their velocity much longer, and therefore range further; for a given range the elongated projectiles will consequently require a less angle of elevation than the spherical shot, their trajectories will be lower, thereby increasing the chance of their striking the object, a greater extent of ground being also covered by them during their flight. The effect of a side wind will depend upon the position of the centre of gravity of the elongated projectile; should the centre of gravity be far forward, the wind will have a greater effect upon the regularity of flight of the projectile than if it is as nearly as possible in the centre of figure. This was the case with the "egg-shaped" bullets* proposed by Robins, the results of experiments with them being given by Colonel Beaufoy, in his work called *Scloppetaria.* "At long distances, that is, from 300 to 600 yards, when fired from a gun of $\frac{6}{10}$ inch bore, they were found much less liable to deviation than at 200 yards and under, with this peculiarity, that in windy weather, whereas balls are usually driven to leeward of the object, these had a diametrically opposite effect. It was found, however, that these balls were subject to such occasional random ranges, as completely baffled the judgment of the shooter to counteract their irregularity." Their deviations to windward no doubt arose similarly to those of rockets, in consequence of the centre of gravity of the projectile being so far forward.

As already explained, with a rifled gun and elongated projectile constructed upon proper principles, the lateral deviation of the latter is reduced to a very small amount, and as it may be considered constant for any given range it can be easily allowed for in practice.

As the elongated bullet does not lose its velocity so quickly as the spherical shot, it does not require so high an initial velocity, and can therefore be fired with a less charge.

The greater the length of the projectile in proportion to its diameter, the longer will be its range, provided it have a sufficiently rapid velocity of rotation. The velocity of rotation must increase with the length of the projectile, its tendency to rotate on its shorter axis increasing with the length, but there are considerable objections to this very rapid velocity of rotation, as increased strain upon the metal of the gun, great deflection of shot, after striking, &c.

It is absolutely necessary to have two grooves, a single one would give a wrong direction; some rifles are made with as many as forty grooves, or even more. The width of the grooves will of course depend upon the number. Grooves must not be too deep, or projections will be formed on the bullet, upon which the resistance of the atmosphere would act injuriously; deep grooving renders the bore difficult to clean and subject to fouling, besides weakening the metal of the gun. If the grooves are shallow and numerous, instead of deep and few in number, less resistance will be

* A great objection to this shaped bullet is that there is no certainty of its longer axis coinciding with that of the bore when placed in, the force of the powder not acting therefore through this axis.

offered to a projectile which expands or is forced into them by the explosion of the charge; also the cylindrical part of the bullet will issue from the bore less deformed in shape, and therefore less liable to injurious effect from the atmosphere, it will preserve its velocity of rotation longer, and in all probability its deflection will be reduced.

The inclination of the grooves is a point of very considerable importance, and very different opinions are held with regard to the velocity of rotation required for projectiles of different lengths. It would appear that no greater velocity of rotation should be given to the projectile than is necessary to maintain it during its flight in the desired direction with its point foremost; for the great deflection after striking in consequence of a rapid rotation is very objectionable, and should the projectile be a shell the pieces would spread laterally to too great a distance.

The velocity of rotation of a shot will depend upon its initial velocity, and the inclination of the grooves or "twist" as it is technically called. In order to find the velocity of rotation of a projectile on leaving the bore, divide the "initial velocity" (in feet) by the number of feet in which one complete turn or revolution is made by the shot; thus in Sir W. Armstrong's 12-pr. the turn is 1 in 36 calibres (1 calibre = 3 inches) or 9 feet, and as the initial velocity is 1080 feet per second,

$$\text{The velocity of rotation will be} = \frac{1080}{9} = 120 \text{ revolutions per sec.}$$

Some rifles are made with what is called a "gaining twist," the grooves having but a slight inclination at the breech, but increasing regularly towards the muzzle; this is the case in the Lancaster rifle. The objection to such an arrangement of the grooves is, that a continually increasing resistance is offered to the ball's progress, while at the same time the velocity of the ball is also increasing; there will consequently be a great tendency to strip when the bullet is made of soft material such as lead, but if of hard material, as in the case of the projectiles of wrought-iron for the Lancaster gun, there will be danger of fracture, either to the gun or projectile.

Charge.

The form and weight of the projectile being determined, as well as the inclination of the grooves, the charge can be so arranged as to give the necessary initial velocity, and velocity of rotation; or if the nature of projectile and charge be fixed, the inclination of the grooves must be such as will give the required results. The most important consideration is the weight and form of projectile; the inclination of the grooves, the charge, weight of metal in the gun, &c., are regulated almost entirely by it. The charges used with rifled pieces are much less than those with which smooth-bored guns are fired, for little or none of the gas is allowed to escape by windage, there being therefore no loss of force; and it is found by experience that with comparatively low initial velocities, the elongated projectiles maintain their velocity and attain very long ranges.

PYROTECHNY, MILITARY.*

AMMUNITION.

Cannon Cartridges. Land and Sea Service.

The bags are made of serge, cut out and completed at the Laboratory for all the different natures of ordnance, according to the various calibres, their charges, and form of the chambers. They are filled by *weight*, and choked, and have one or more bands, according to the dimensions of the cartridge, to add to its strength and

* From the Royal Laboratory, Woolwich, by permission of Lieut.-Col. Boxer, Superintendent.

security. Cannon cartridges vary in weight from 20lbs. for the 68-pr. of 112 cwt. down to 6 ozs. for the 1-pr. brass gun amusette.

Fig. 1 represents a filled cartridge for 32-pr.]

Fig. 2. represents a filled cartridge for 24-lb. howitzer.

Fig. 1.

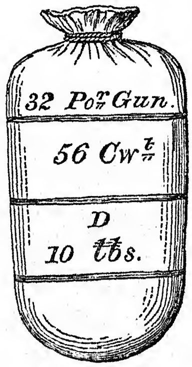
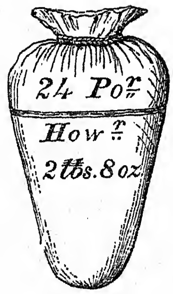


Fig. 2.



All filled cartridges supplied to Sailing Vessels of the Royal Navy are stowed in square wooden cases, copper-lined, the mouth of which is firmly secured with a luted bung, and again by the lid of the case, fastened with a metal key, and on the lid is marked its contents. These different cases are distinguished by *black letters* when they contain the distant charges,—by *light blue* for the full charges, and by *red letters* for the reduced charges.

Fig. 3 represents a whole case, closed. Fig. 4, the same open.

Fig. 5, the same, side view, showing the rope-handles.

Fig. 3.

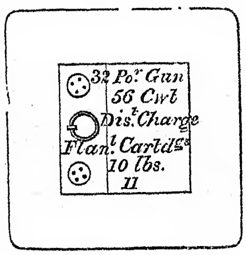


Fig. 4.

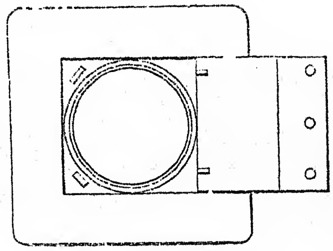


Fig. 5.

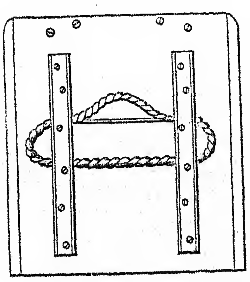


Fig. 6.

Bung.

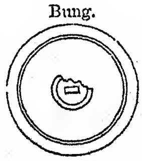
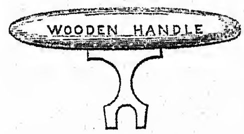


Fig. 7.

Metal Key.



A whole case will stow 110 lbs. of powder in cartridges,—the half and quarter cases in proportion. Besides the cannon cartridges, all the small-arm ammunition and other combustible stores for Sea Service, such as blue lights, long lights, portfires, &c., &c., are packed in these different copper-lined cases. They are manufactured in the Royal Carriage Department, are very durable, and capable of standing much hard service, and generally repairable. The cost of a whole case is £1 14*s*. 10*d*.

All filled cartridges for H.M. steamers are stowed in metal cases, the mouths of which are similarly secured, and the lids marked with their contents, in colours, as on wood copper-lined cases. They are of pentagonal form; the number of filled cartridges they will contain is the same as the wooden cases, and, like them, they are also divided into whole, half, and quarter cases. There are also sectional cases, for filling up the sides.

Fig. 8.

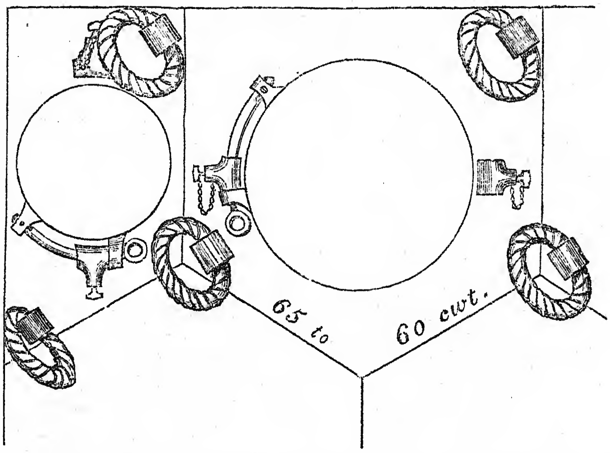


Fig. 8 represents the plan of a metal case, with a sectional case to hold rifle ammunition.

Note.—All boat ammunition for steamers is stowed in metal-lined cases, the same as for sailing vessels.

Filled cannon cartridges for Land Service are kept in magazines, stowed in ammunition boxes. These cartridges are, however, generally limited in number, according to circumstances.

Storekeepers and others in charge of magazines are supplied with cartridge bags ready for filling when required. These empty bags are now sent to stations at home and abroad, and for both Land and Sea Service in pressed bales, containing numbers varying from 200 to 500 and upwards. A screw hand-press, capable of considerable power, is used for this operation. A covering of oil-cloth is also pressed over the bags, together with a stout canvas covering, well secured and marked.

Fig. 9.

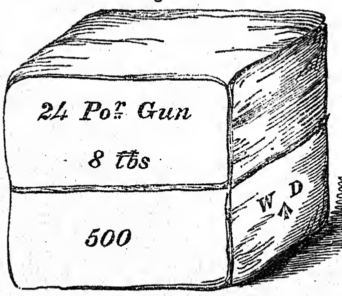


Fig. 10.

Fig. 9 represents a bale of 500 24-pr. cartridge-bags, as packed for Land Service.

Fig. 10 represents a bale of 200 32-pr. cartridge-bags, as packed for Sea Service.

Rifle Cartridges. For the construction of a cartridge the paper is cut into three unequal trapeziums. Two of these are rolled together round a former, to make the powder cylinder, the end of the longer one being folded up into a hollow at the bottom of the former, into which the paper is pressed with a forming-plug, shaped like the head of a bullet. The point of the bullet is pressed into the cavity thus formed, and the other paper is then rolled round the bullet and cylinder, the lower half-inch being folded on the base of the bullet, and there tied. A narrow band is pasted round the cylinder, to cover the top of the outer paper. (Figs. 11 and 12 are half-size.) The former is then with-

Fig. 11. Former.

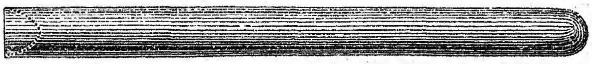
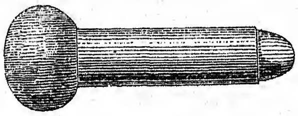


Fig. 12. Forming Plug.



drawn, and the cartridges are placed upright in rows in a box. They are then filled successively by a machine, and after each has received the proper charge, the top is choked by taking the open end between the finger and thumb, and twisting the paper once round close to the powder.

Cartridges, of all natures, are placed together in bundles containing ten each: for ball-cartridges a slip of paper is used, the cartridges being placed with the balls end to end, over and under the slip; they are then packed in strong white wrapping paper, tied across each way, and on the paper is printed the nature of cartridge and charge. Blank cartridges have no slips of paper between them, and are packed in purple paper, the same as the cartridges are formed with.

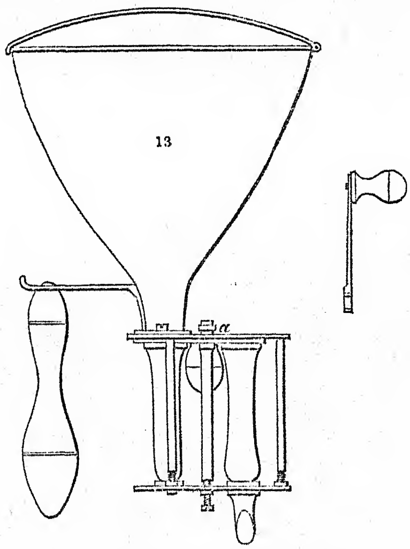


Fig. 13, machine for filling small-arm cartridges, with the lever or handle by which the measures are moved, and which is fixed at a.

The measures are fixed vertically in a circular plate, opposite to each other, with an axis between them, upon which they work between two other plates.

On the top of the plate a hopper is fixed, communicating alternately with the measures and filling them; and on the opposite side, in the bottom plate, is a hole with a spout, through which the discharge takes place. The plates are framed together by three pillars having double adjusting nuts on each, to regulate the distance of the plates.

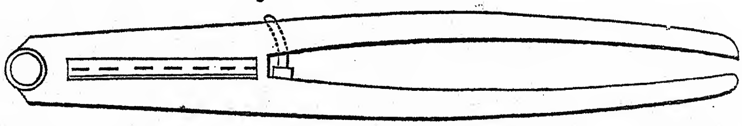
The measures are moved by a handle or lever, the motion of which is limited by the pins, and which, while it presents one under the hopper to receive, places the other immediately over the discharging hole for delivery, so that the two operations of filling and discharging are going on at the same moment. The bottom of each measure is contracted, to retard, in a small degree, the discharge, so as to secure one measure being filled before the other is emptied. A hole is cut in the top plate over the discharging measure, by which it may be ascertained that it is always full, as well as that the whole contents are delivered.

Note.—Ball-cartridges for all arms are packed in quarter-barrels, and blank cartridges in half-barrels. The corresponding number of copper caps, with 50 per cent. additional for the former, and 10 per cent. additional for the latter, are packed in zinc cylinders, placed in the centre of each barrel.

Ball, Spherical.

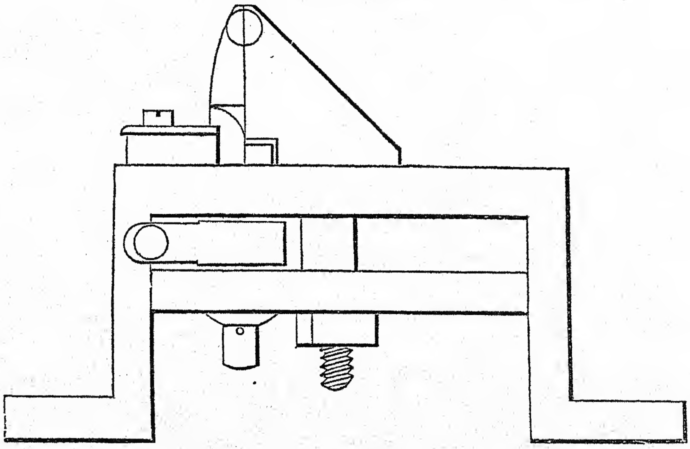
Spherical balls are now used only for the diaphragm shell. They are made of a composition of lead and antimony. The metal is melted in a large round iron pot, set in brickwork, but must never be made red-hot. The metal is dipped out with ladles

Fig. 14.—Ball or Bullet Mould.



and poured into moulds (fig. 14), of which there are three to each bench, employing two men, one casting, the other removing the balls from the moulds with a pair of pliers, and placing them in a box. The services of one man are also required to

Fig. 15.—Nipping Machine.



attend the fire. The men employed change about with every box they cast. A tub

of water is kept under each bench, to cool the moulds; but in so doing, it must be particularly observed that the moulds are only to be dipped into the water when the balls are in them, and also that they are kept tight, to prevent the water getting within, which would be dangerous to the men casting.

Note.—Two boys nip the same quantity as three men cast per day, and in this operation one boy cuts off the backs with the nipping machine (fig. 15), and the other afterwards examines the balls. These boys also change alternately.

Enfield Bullet. The bullet now in use is known as the Enfield; it is cylindro-ogivale in form, with a truncated conical hollow at the base, into which a hard wood plug is inserted. It is 1·095 inch long and ·55 inch diameter. The mode of forming these bullets is as follows:—The lead (which should be pure) is melted in an iron pot, and then run into a strong iron cylinder, holding about $4\frac{1}{2}$ to 5 cwt., and made with an aperture about 8 inches diameter at the top. Above the cylinder is fixed a strong block of iron with a plunger or ram, of the same diameter as the aperture in the cylinder, attached below it. Both block and plunger are perforated throughout their length, and a die, having a hole through it of the proper diameter, is inserted in the bottom of the ram. After the lead has been allowed to cool for about ten minutes, the cylinder containing it is forced upwards by hydraulic pressure till the plunger enters it, when the lead is squirted up through the die, and comes out at the top of the block in the form of a continuous metal rod, which is then drawn over, with a woollen shield to the hand, and wound on a reel.

The rods are next wound off on to other reels suspended over the bullet-forming machines, four of which, when in gear, are set in motion by one band and two fly-wheels. Each of the fly-wheels acts upon a heavy cross-head, which works, with an alternate motion, a long bar with a nipple at each end, by which the cavity in a bullet is formed. This cross-head moves two iron hands, which press on the teeth of a pinion at each end alternately; the pinion works a roller, which by friction on another roller draws down the leaden rod and guides it between a pair of nippers, which cut off the right length of rod, and opening, drop it down, and catch it below at the moment when the before-mentioned nipple reaches that point, and presses the lead into a hole, giving the form of the front of the bullet, while the nipple makes the cavity and stamps the government mark. As the nipple withdraws, a lever, acted upon by a cam, pushes forward a part of the mould, and throws out the bullet completed.

Fig. 16.—Elevation of Bullet.

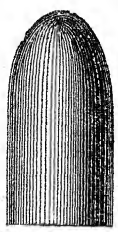
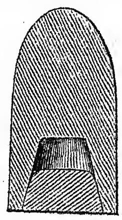


Fig. 17.—Section with plug.



Balls, Light. Light-balls are of four different natures, called 10-inch, 8-inch, $5\frac{1}{2}$-inch, and $4\frac{2}{5}$-inch. Their form is oblong. The skeletons are made of wrought iron, and are coated with canvas called Osnaburg, which is 24 inches wide. The canvas must be cut sufficiently long to wrap twice tightly round the skeleton, and stitched first up the seam, and then at the top and bottom of each bar, with a needle and twine, taking care to clip the canvas with a pair of scissors opposite each bar, and then turning in the cut part between the bars at the bottom, to prevent the composition coming out

when the skeleton is being filled. Four holes are to be cut in the quarters for filling and priming.

Composition for ground light-balls.

	lbs.	oz.	drs.
Saltpetre, ground	6	4	0
Sulphur	2	8	0
Resin, pounded	1	14	0
Linseed oil, boiled	0	7	8

The method of preparing the composition is the same as for carcasses.

It must be observed, while filling, to press the composition well to the canvas, inside, to make it as round as possible, and after it is well filled, put in the wooden plugs for forming the priming-holes. These plugs must be well greased and fastened down, and the ball then put by to cool. They are next to be woolded with such sized quilting line as will admit of their passing freely through the gauge. The plugs are then taken out and the holes driven with fuze composition, the same as fuzes; and as the holes run the same size as the bores of fuzes, the same sized drifts will answer for driving them,—then primed with quick-match, and the holes covered with paper. The whole receives two coats of lead-coloured paint, and afterwards a barras cap, kitted and put over the top, and sprinkled with sawdust.

Table of the Weights of Oblong Light-Balls.

Nature.	Empty.	Coated.	Filled.	Woolded.	Primed.	Finished.
	lbs. oz.	lbs. oz.	lbs. oz.	lbs. oz.	lbs. oz.	lbs. oz.
10-inch.	33 0	33 10	68 14	69 8	70 4	71 2
8 ,,	15 12	16 1	32 14	33 2	33 10	34 0
$5\frac{1}{2}$,,	1 8	1 10	8 6	8 8	8 9	8 12
$4\frac{2}{5}$,,	1 2	1 4	4 9	4 11	4 12	4 14

Suspended Light Balls.

These are provided with an apparatus by which they are rendered capable of remaining suspended in the air for a short period over an enemy's works. They are composed of

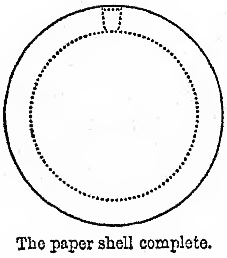
	lbs.	oz.
Saltpetre	7	0
Sulphur	1	12
Sulphide of arsenic	0	8

Balls, Smoke.

Smoke-balls are of five different natures, viz., 13-inch, 10, 8, $5\frac{1}{2}$, and $4\frac{2}{5}$-inch. The cases are formed on a wooden ball, which is made of ash or other hard wood. This ball is to be well greased with tallow, to prevent the paper which is to form the skeleton from sticking to it. The paper is cut into strips about $3\frac{1}{2}$ inches wide, and long enough to wrap once round the ball or former. These strips are put into water, and when soaked a little, are to be taken out and pasted: one of these is then laid round the former, commencing at a certain point, and brought up to it on the other side. Both sides of the paper are to be notched with a pair of scissors, and the clipped parts laid regularly down, not allowing one of the pieces to lay over the other. Two round pieces of paper are then cut and pasted on each end; these must also be clipped to make them lay close to the former. The first coat should only be slightly pasted; a second coat is then put on in the same manner as the first, except that the long slip is laid the contrary way. In this manner the ball is to receive four coats, laying the paper the contrary way each coat. It must then be left to dry, and when

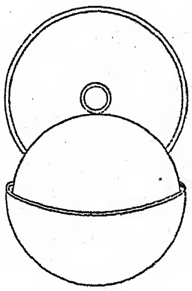
quite so, it is cut through with a sharp knife down to the wood, nearly all round, leaving about $1\frac{1}{2}$ inch to form a hinge. The case is now to be opened by tapping it gently all over with a small mallet, and easing it with a knife until the former will come out. Strips of paper are then pasted over the joint, pressing it equally together. When it is perfectly dry, four more coats are put on as before, and so continued unti the ball is brought up to the gauge. The fuze-hole is next bored with a Reimer, and then enlarged to the proper size with a round hot iron.

Fig. 18.



The paper shell complete.

Fig. 19.



The first four coats of paper cut through, to get out the former.

Table of the Dimensions of Formers and Wood Gauges for Smoke-Ball Cases.

Nature.	Diameter of the wood ball or former.	Thickness of paper complete.	Diameter of wood gauges.	Diameter of fuze-hole. At top.	Diameter of fuze-hole. At bottom.
	Inches.	Inch.	Inches.	Inch.	Inch.
13-inch	11·3	1·45	12·75	1·837	1·696
10 ,,	8·6	1·15	9·75	1·57	1·45
8 ,,	6·65	1·1	7·75	1·325	1·227
$5\frac{1}{2}$,,	4·75	·79	5·54	·894	·826
$4\frac{2}{5}$,,	3·75	·65	4·4	·832	·769

		lbs.	oz.
Composition.—	Corned Powder, bruised	5	0
	Saltpetre, pulverised	1	0
	Sea-coal, pounded	1	8
	Swedish Pitch	2	0
	Tallow	0	8

The pitch and tallow are put into an iron pot, fitted into a copper, and filled with common sweet oil, which is made very hot; the saltpetre and sea-coal are then added. These ingredients, when well amalgamated, remain over the fire about a quarter of an hour: it is then transferred into a cooler pot, to prevent accident when the powder is added. The whole is mixed well together. The composition is then taken out and placed upon a board to cool, and small portions at a time are taken in the hand to fill, and pressed in with a wooden drift. A wooden plug is put in for forming the priming-hole, and which must be well greased and tied down, to prevent the composition from forcing it out. When cold, the plug is taken out, and the hollow driven with fuze composition, and primed with quick-match, the same as a common fuze.

The following are the proportions of dry composition put into smoke-balls, for the purpose of occasionally clearing the vent :—

For 13-inch	Sulphur . .	2 oz.	One of these proportions is put into the case each time, viz. when $\frac{1}{4}$ filled, $\frac{1}{2}$ filled, and $\frac{3}{4}$ filled, according to the nature of the smoke-ball.
	Sea-coal . .	2 ,,	
,, 10-inch	Sulphur . .	1 ,,	
	Sea-coal . .	1 ,,	
,, 8-inch	Sulphur . .	$\frac{1}{2}$,,	
	Sea-coal . .	$\frac{1}{2}$,,	

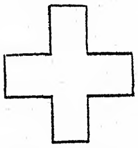
For the $5\frac{1}{2}$ and $4\frac{2}{5}$-inch, a small quantity of each put in twice is sufficient.

Smoke-balls have lastly three coats of lead-coloured paint on the outside.

Caps, Copper. All copper caps for the service of the Army and Navy are manufactured at the Royal Laboratory, and are of one pattern only for every nature of small-arm. The Government caps differ in make and form from those of general manufacturers. There is more copper in them, having a flange or rim, for the purpose of giving a firmer hold to those using them: a more extensive process is also adopted, to secure the composition from deterioration, either from damp magazines or the effects of climate, to which the caps are exposed in every part of the globe.

The copper is annealed, to render it less brittle, and is pickled in dilute sulphuric acid, to clean off the effects of the fire. The sheets are then cut into strips either 2 inches or $2\frac{5}{8}$ inches wide, the former to make three, the latter four, caps in width. The strips are next oiled, and then placed in a machine, where they are drawn through rollers and cut into crosses $\frac{3}{4}$ in. diameter. These crosses are received in a die, which forms the caps and affixes the government mark to each. As soon as one strip leaves the machine another is inserted and the process repeated. The caps are then shaken in a drum with saw-dust, to remove the oil, and afterwards arranged in brass plates for loading, each plate containing 1000 caps.

Fig. 20.



The plate of 1000 caps is then passed to the loading machine to receive the charge, which consists of fulminate of mercury and chlorate of potassa, with a very small quantity of finely-powdered glass. The composition is next pressed firm into each cap by a machine, and then receives a coating of varnish, consisting of a mixture of shell-lac and spirits of wine. This varnish affords great security in resisting damp and the effects of climate, and fixes the composition firmly in the cap. The caps are placed upon a steam-bath, to dry and harden the varnish. They are once more shaken in a drum containing very fine saw-dust, to render them perfectly bright, and are then ready to be packed for service.

Copper caps for the Land Service are first packed in parcels of 15 each for 10 rounds of ball-cartridge. Six of these parcels are then placed into one, making the due proportion of caps for 60 rounds of ball, and are thus stowed in zinc cylinders with the ammunition. Blank cartridges have 25 caps similarly packed for 20 rounds, and 75 caps for 60 rounds.

Copper caps for the Naval Service are placed in stone jars, glazed within and without, and secured at the mouth with a covering of India-rubber, each jar containing 1000 loose caps.

The usual rate of manufacture is about 2,000,000 caps per week.

Carcasses. Carcasses for Land and Sea Service are of eight different natures, viz. 13-inch, 10, 8, $5\frac{1}{2}$, and $4\frac{2}{5}$-inch; 42-pr., 32-pr., and 18-pr. The skeletons or cases are similar to common shells, but with three or four fuze-holes, and the ingredients for filling as follows :—

	lbs.	oz.
Saltpetre, ground	6	4
Sulphur, ditto	2	8
Resin, pounded	1	14
Antimony, ditto	0	10
Tallow	0	10
Venice Turpentine	0	10

The dry ingredients are well mixed together with a copper slice, and afterwards passed twice through a fine hair sieve. The turpentine and tallow are put together into an iron pot (which fits into a copper containing about 27 gallons of oil), to be well melted; the dry ingredients are then added, stirring with an iron paddle for 15 or 20 minutes, until the sulphur begins to run. The whole is then taken out of the pot with a ladle, a little at a time, and laid to cool on the lead covering of the copper. Before the filling is commenced, corks are driven into all the holes except one. The carcasses are then filled by forcing in the composition with a wooden drift through a tin funnel, taking great care that it is filled solid: the corks are next taken out, and priming-plugs, well greased, are forced in and fastened down until the composition is quite cold. These plugs are then withdrawn, and all the holes driven with fuze composition and primed with quick-match, the same as common fuzes. Lastly, a barras cap, kitted and cut larger than the holes, is laid on and sprinkled with sawdust.

Table of the Weights of Round Iron Carcasses.

Natures.	Empty.				Weight of composition.		Total Weight.			
	cwt.	qrs.	lbs.	oz.	lbs.	oz.	cwt.	qrs.	lbs.	oz.
13-inch . .	1	2	27	0	17	14	1	3	16	14
$11\frac{1}{2}$,, . .	1	1	3	8	10	8	1	1	14	0
10 ,, . .	0	3	6	4	7	4	0	3	13	8
8 ,, . .	0	1	20	0	2	14	0	1	22	14
$5\frac{1}{2}$,, . .	0	0	15	6	1	$3\frac{1}{2}$	0	0	16	$9\frac{1}{2}$
$4\frac{2}{5}$,, . .	0	0	8	6	0	7	0	0	8	13
42-pr. . .	0	1	0	14	1	12	0	1	2	10
32 ,, . .	0	0	23	$3\frac{1}{2}$	1	$4\frac{1}{2}$	0	0	24	8
18 ,, . .	0	0	13	12	0	11	0	0	14	7

Fuzes, Wood. Wooden fuzes are of two classes, viz. gun and mortar, 13-inch, 10, 8, $5\frac{1}{2}$, and $4\frac{2}{5}$-inch, and are of the four following dimensions:—

Nature.	Total Length.	Exterior. Diameter.		Cup.		Bore.		Length of solid bottom
		Top.	Bottom.	Diam.	Depth.	Diam.	Length.	
	Inches.	inches.	inch.	inch.	inch.	inch.	inch.	inch.
13-inch, 10 ,, 8 ,,	7·4	1·565	·77	·8	·3	·37	6·6	·5
$5\frac{1}{2}$,, $4\frac{2}{5}$,,	4·1	1·09	·67	·62	·25	·275	3·65	·2
Common	3·15	1·09	·75	·62	·25	·275	2·6	·3
Diaphragm	2·0	1·09	·87	·62	·25	·275	1·6	·15

The 13-inch fuzes are graduated to 8 inches; the 10 to 7 inches; the 8 to 6 inches;

the $5\frac{1}{2}$ to 4 inches; and the $4\frac{3}{8}$ to 3 inches, and subdivided into ·2. The 8 and $5\frac{1}{2}$-inch spherical are graduated to 1 inch, and also subdivided into ·2. These fuzes are driven with fuze composition, one inch of which must burn five seconds, neither more nor less, or the calculation for firing shells would be rendered useless.

Composition.—	Saltpetre, pulverised	3lbs.	4 oz.
	Sulphur, sublimed	1lb.	
	Pit-mealed Powder	2lbs.	12 oz.

The above-named ingredients are mixed well together by a copper slice, and then passed through a fine hair sieve three times, and afterwards through a lawn sieve. It is then to be well rubbed with the hands, and with a copper shovel put into the composition tub.

It is to be observed, that unless the composition is well mixed, it will not answer for fuzes, as their efficiency depends upon the manner of mixing and driving the composition; that no other powder will answer for fuze composition but that which is made of pit charcoal; and that for all composition in which charcoal and mealed powder form a part, the sieve in which it is mixed must have a top and bottom, to prevent the finer particles from flying about, which would not only be disagreeable to the mixer, but would rob the composition of its strength.

The fuzes are set in a frame, and the composition (previously formed in little pellets) placed in them. The frame is then forced up by hydraulic pressure against a fixed block provided with drifts, which enter the fuzes and press the composition firmly together.

The fuze is placed in a socket, and a little of the composition on the top loosened with a pricker. The quick-match is cut to the proper length required, doubled, and put into the centre of the cup with a mallet and drift, then a ladleful of pit-mealed powder, pressed in firmly enough to lift the fuze out of the socket; and the ends of the quick-match are laid inside the cup. Lastly, a mixture of mealed powder and spirits of wine is laid over the match, and the top dipped into mealed powder, and then the fuze is set aside to dry.

A circle of strong rocket-paper is cut to the size of the fuze and laid on the cup, with a piece of tape attached; a tin cap is then laid over it and left till the shell is in the gun or mortar, when it is removed by means of the tape.

Fuzes, Metal (Naval Service).

Metal fuzes are of three natures, viz. the $7\frac{1}{2}$ seconds fuze, driven with mealed powder; the 20 seconds fuze, driven with fuze composition; and Moorsom's percussion fuze.

The time fuzes are driven and primed precisely the same as wooden fuzes, but instead of being capped as above, have a screw metal cap. The holes for ignition are bored right through the metal, and a cylinder of rocket-paper is inserted to contain the composition.

The fuzes are screwed into the shells, the holes of which are bouched with metal to receive them; they are screwed in to the right hand, and the cap to the left, so that the latter when unscrewed may not disturb the fuze.

Note.—The diameter of the fuze-holes for all natures of shells fitted to receive metal fuzes is precisely the same.

Lights, Signal and Long.

The following is the composition for signal and long lights:—

Saltpetre, ground	7lbs.	0 oz.
Sulphur, do.	1lb	12 oz.
Sulphide of Arsenic	0lb	8 oz.

The cases are made of brown paper, slightly pasted and rolled on a wooden former, in the same manner as common portfire cases: they are made to the same diameter as

the 1-℔. signal rocket, the same cylinder-gauge being used for them. The long light case is cut to the length of 9·25 inches, one end of which is perforated at an inch from the bottom, to allow a wooden pin to pass through it, for the purpose of attaching the handle to the case.

Long lights are driven on a wooden nipple, 2 inches in length, and of the same diameter as the cylinder former for the 1-℔. signal rockets. A circle of paper, of the same diameter as the interior of the case, is placed on the nipple, and a ladleful of clay driven hard upon it; then pellets of composition are put in, and pressed hard in succession by means of the hydraulic press, in the same manner as the fuzes, till the case is nearly full, when it is taken off the nipple, and primed, and a sort of small friction-tube inserted, which, when pressed, ignites the priming. They afterwards receive two coats of paint. A long light will burn five or six minutes.

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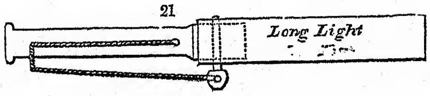


The signal light is made in exactly the same manner, but the composition is only about 1 inch thick, and burns about one minute.

Match Quick.

The following is the composition of quick-match:—

Cotton	1 ℔. 12 oz.
Cylinder-mealed powder	10 ℔s. 0 oz.
Gum-water	4 quarts.

The saltpetre is put into a pan and the end of the wick secured to one of the handles to unwind the cotton from the bale; the last end is fastened to the other handle of the pan; the water is poured upon the cotton, which is then covered with one-third of the mealed powder, and so left for about six hours to get well soaked: the last end of the wick is then secured to one of the handles of another pan, and the wick drawn gently through the hand into it, taking care that no part of the cotton passes uncovered. The second portion of the mealed powder is then added, and the liquid in the first pan poured upon it, and left to stand the same time as before. One end of the wick is next fastened to the reel, and wound on to it tight. When the whole is wound out of the pan, the reel is taken off the stand, and laid on two battens on the table. Next sift half the remaining powder equally over the upper side, and turning the reeling-frame, sift the rest over that side. The match is then set aside to dry.

Match, Slow.

Slow-match is merely hempen rope loosely twisted and dipped in a solution of saltpetre and lime-water.

Note.—A yard of slow-match will burn about three hours.

Portfires, Common.

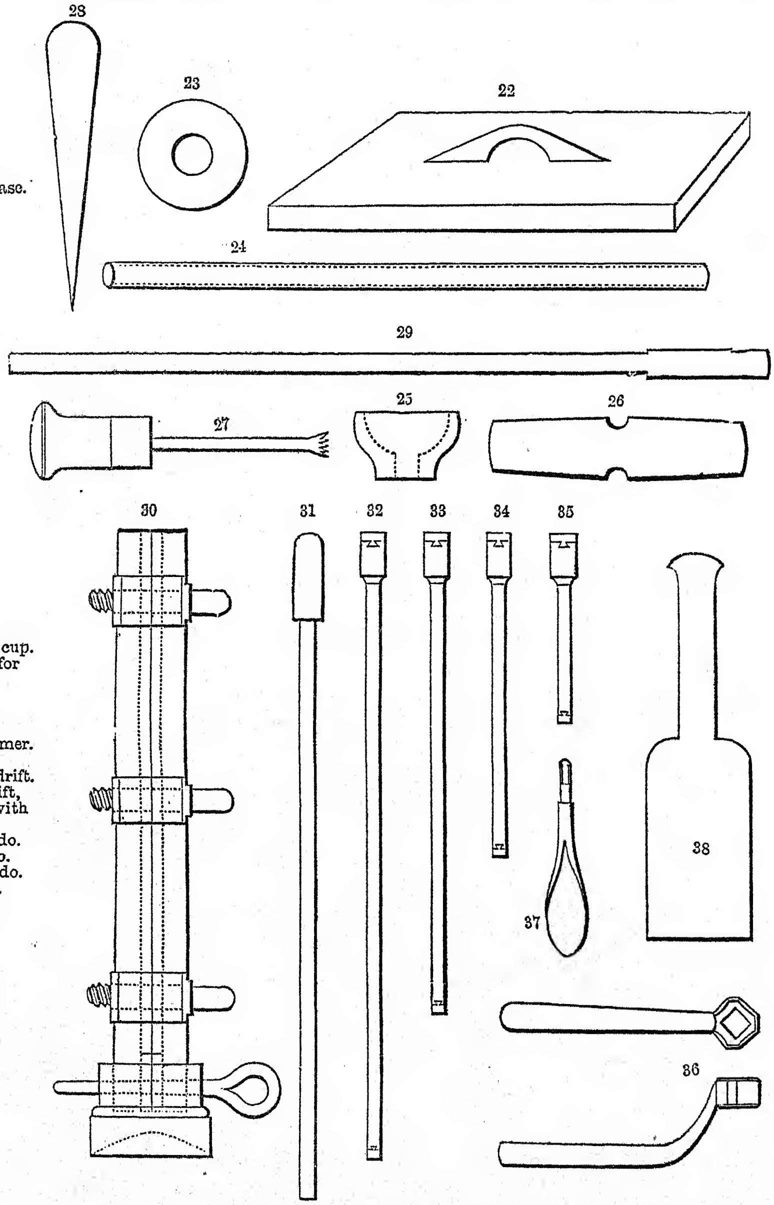
Portfires are of four different natures, viz. Common Portfires, Percussion Portfires, Miners' Portfires, and Slow Portfires.

One-third of the sheet of paper used for this purpose is cut off lengthwise, and the whole is pasted thinly all over; the part cut off is then placed on the centre of the remaining two-thirds, and with the iron former, well pasted, is rolled on it upon a board for the purpose: when supposed to be sufficiently rolled, it is tried with a gauge 7-10ths of an inch in diameter, adding or reducing the paper accordingly. The former is next taken out, and the case laid to dry.

Brimstone, sublimed	2 ℔s.
Powder, cylinder-mealed	1 ℔.
Saltpetre, pulverised	6 ℔s.

The case being thoroughly dry, the bottom is turned in with a brass pricker,

to form a good bottom. It is then placed in the mould with the setting drift in it, which is driven to the bottom of the case with a few blows of the mallet; the mould is then screwed up tight, and the drift taken out. A wooden cup, to prevent



22. Rolling board.
23. Gauge.
24. Empty case.

25. Wooden cup.
26. Handle for bridle.
27. Brass pricker.
28. Fid.
29. Iron former.
30. Mould.
31. Setting drift.
32. First drift, tipped with brass.
33. Second do.
34. Third do.
35. Fourth do.
36. Wrench.
37. Ladle.
38. Mallet.

waste of the composition, is placed on the mouth of the case, above the top of the mould, and the case is cut off level with the inside of the cup, and opened with a

wooden fid, to admit the drift. Commence driving by taking a ladleful of composition and the longest drift, giving it fifteen blows with a 10-inch fuze mallet: when the composition is high enough, the second drift is used, and afterwards the third and fourth. When the portfire is driven, the cup is taken off, and the case cut off level with the mould. Portfires are primed with mealed powder and spirits of wine, and receive two coats of paint before they are issued for service.

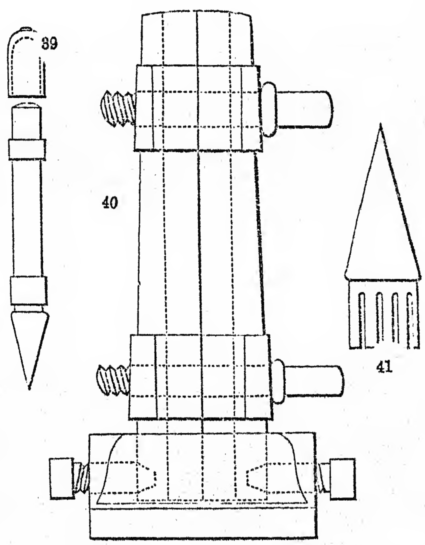
Note.—A common portfire will burn fifteen minutes.

Portfires, Percussion.

The cases are made of signal-rocket paper, folded and cut in the same manner as for ½-lb. signal rockets. The paper is thinly pasted all over and rolled on a former; it is then taken off the former and dried, and one end turned in to form the bottom, and afterwards cut to the length of 10¾ inches. The collars and caps are made of the same kind of paper as the cases, and rolled on a wooden former 1·3 inch in diameter, and brought up to the 1-lb. signal rocket cylinder-gauge. The piece formed for the cap is choked at one end, tied with Dutch thread, and trimmed with a sharp knife to form a neat rose. On the top it is cut to the length of 2·8 inches: the collars are of the same diameter, and cut to three-quarters of an inch long.

Brimstone, sublimed	4 lbs.
Powder, cylinder-mealed	1 lb.
Saltpetre, pulverised	8 lbs.

These portfires are driven in a ½-lb. signal-rocket mould, having two screws at the bottom to secure it; eighteen blows are given to each ladleful of composition with a pound signal-rocket mallet. When the composition is within half an inch of the top of the case, the portfire is taken out of the mould and cut to the length of 9½ inches. The edge of the case is trimmed a little lower than the composition, so as to form a round top. A tin point or cone, filled with resin, is fitted to the bottom or turned-in end, moulding the clipped parts over with kitted twine, and pasting a slip of fine white paper over it: the collar is glued on at the mark made by the gauge. When dry, the paper cap is fitted on, and they receive two coats of paint.



39. Portfire complete.
40. Mould.
41. Tin Point.

The percussion priming is added to these portfires at the stations where they are used (principally for the Coast-Guard), and is simply a small glass globule containing sulphuric acid. This is imbedded in loose composition, which ignites on the globule being broken.

Note.—A percussion portfire will burn five minutes.

Portfires, Miners'.

The cases are made of fine white paper by cutting the sheet into six equal parts; one of these parts is thinly pasted about ¾ths of an inch on one edge, and rolled

tightly on an iron former; when this is sufficiently done, they are laid to dry, previous to filling.

Saltpetre, pulverised	8 oz.
Sulphur, sublimed	8 oz.
Powder, cylinder-mealed	1 lb.

A copper funnel is placed in the mouth of the case, turning in the other end to form a bottom. Fill the funnel full of composition, and put the drift through into the case, keeping it moving till it is nearly full. These cases may be joined together, to make any length required, by cutting off the end that was turned in, and placing it in the mouth or open end of another case, and securing it with a piece of Dutch thread.

Miners' portfires are packed for store in brown-paper parcels containing 100 each.

Portfires, Slow. The paper, which is called blue sugar-loaf paper, is wetted by dissolving 12 ounces of saltpetre in one gallon of water; each sheet is wetted separately on both sides with a brush, one side being dried before the other is made wet: when both sides are thoroughly dry, they are to be well rolled with a rolling board until they are hard and solid; the outer edge is then pasted and laid closely down. In rolling these portfires, one end should be formed conical, and the other cut off fair to the length of 19 inches.

Slow portfires burn from three to four hours each.

Rockets, Congreve. Congreve rockets are of four different natures, viz. 24-pr., 12, 6, and 3-prs. The cases are made at the Laboratory, of wrought iron, and although upon a much larger scale, are driven upon the same principle as signal rockets. The power is given by the fall of what is termed a monkey, the weight of which is in proportion to the nature of the rocket to be driven.

Congreve rockets may be used either as shot or shell rockets, and the shell made to burst either at long or short ranges, as required. Every rocket is fitted with a fuze screwed into the base of the shell; this fuze is as long as the size of the shell will admit of, so as to leave sufficient space between the end of it and the inner surface of the shell, for putting in the bursting powder; and the end of the fuze is cupped, to serve as a guide in the insertion of the boring-bit. There is a hole in the apex of the shell, secured by a screw metal plug, for putting in the bursting powder and for boring, according to the different ranges at which it may be required to burst the shell.

The following stores and implements form part of the present Rocket Equipments:

Bursting powder, fine-grain, made up in bags, and marked according to the nature of the rocket.

Funnels for loading the shells.

Boring stocks or braces.

Boring-bits, of the same diameter as the fuze composition, fitted with brass graduated scales, and of a length sufficient to bore to within $1\frac{1}{2}$ inch of the top of the cone in the 24-pr. rocket, and to within 1 inch of the top of the cone in the 12, 6, and 3-prs.

Turnscrew-bit for the plug.

Grease for the boring-bits.

In Field Service, the bursters are carried in the limber-boxes, in canvas cartouches similar to those in which the field ammunition is carried, and the small stores in a box on the body of a carriage opposite, and corresponding to the slow-match box.

For Her Majesty's Ships of War, the bursters are issued in the metal-lined cases of the Service, and the small stores in a box made for the purpose.

For Garrisons or other occasional demands, the bursters are issued in the packing cases now in the Service, and the small stores in a box made for the purpose.

General observations on firing rockets.

If the rocket is to be used as a shot rocket, the only thing to be attended to is to take care that there is no powder in the shell, and that the plug is secured in the plug-hole. If the rocket is to be used as a shell rocket at the longest range, the plug is to be taken out and the shell filled, the fuze left at its full length, and the plug replaced.

If at the shortest range, the fuze is to be entirely bored through, and the rocket composition bored into, to within 1½ inch of the top of the cone in the 24-pr. rocket, and to within 1 inch in the 12, 6, and 3-pr. rockets. The distances from the surface of the shell to the top of the cone, and from the surface of the shell to the end of the fuze, and also the length of the fuze, being fixed and known, the place on the boring-bit at which to screw the stopper, whether for various lengths of fuzes, or lengths of rocket composition to be left over the cone, is easily determined: these distances are marked on the brass scales for each nature of the rocket; and the length of rocket composition available for boring into, and the lengths of fuse, are also set off and subdivided into tenths of an inch.

24-*Pounders.*—If the whole length of the fuze is left in the shell of the 24-pr. rocket, it may be expected to burst at about 3300 yards; elevation 47 degrees.

If the whole of the fuse composition is bored out, and the rocket composition left entire, the shell may be expected to burst at about 2000 yards; elevation 27 degrees.

If the rocket composition is bored into, to within 1·5 inch of the top of the cone, the shell may be expected to burst at about 700 yards; elevation 17 degrees.

12-*Pounders.*—If the whole length of fuze is left in the shell of the 12-pr. rocket, it may be expected to burst at about 3000 yards; elevation 40 degrees.

If the whole of the fuze composition is bored out, and the rocket composition left entire, the shell may be expected to burst at about 1300 yards; elevation 20 degrees.

If the rocket composition is bored into, to within 1 inch of the top of the cone, the shell may be expected to burst at about 500 yards; 10 degrees' elevation.

6-*Pounders.*—If the whole length of fuze is left in the shell of the 6-pr. rocket, it may be expected to burst at about 2300 yards; 37 degrees' elevation.

If the whole of the fuze composition is bored out, and the rocket composition is left entire, the shell may be expected to burst at about 950 yards; elevation 15 degrees.

If the rocket composition is bored into, to within 1 inch of the top of the cone, he shell may be expected to burst at about 500 yards; elevation 10 degrees.

3-*Pounders.*—If the whole length of the fuze is left in the shell of the 3-pr. rocket, it may be expected to burst at about 1850 yards; elevation 25 degrees.

If the whole of the fuze composition is bored out, and the rocket composition is left entire the shell may be expected to burst at about 750 yards; elevation 12 degrees.

If the rocket composition is bored into, to within 1 inch of the top of the cone, the shell may be expected to burst at about 500 yards; elevation 8 degrees.

Rockets, Signal.

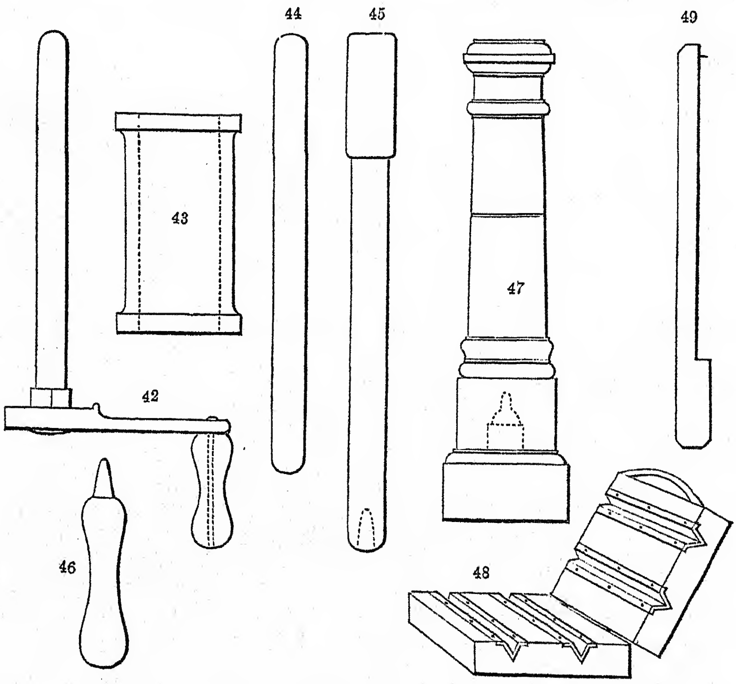
Signal rockets are of two natures, viz. 1-lb. and ½-lb. rockets. The cases are made of sheets of strong paper, which are 2 feet 5 inches in length and 1 foot 11 inches in width. They are turned upon a brass turner by taking one turn round it, and keeping the paper very tight with the left hand; it is then pasted thinly within 3 or 4 inches, and rolled up. The case is then next taken to a press and rolled, by turning it round lightly at first, until it is set to the former. A weight is put on the press, and the former turned by the handle until it is of proper size to admit the case passing through the cylinder-gauge, adding or reducing the paper as required. It is then removed from the former to be choked, which is done by placing the hide round it, close up to the cylinder-gauge, and pressing the treadle with the foot, working the case at the same time. It is then tied tight with six or seven half-hitches of packthread. Slip the gauge to the bottom of the case, and set the choke on a nipple by putting in the setting stick, and giving it eight or nine blows with a mallet. It is then marked

with a gauge to the length it is to be cut, and, when sufficiently dry, the case is ready for driving.

The process for forming all signal-rocket cases is precisely similar for each size, except in the weight used upon the press, which is 1 cwt. for the 1-lb. rocket, and ½ cwt. for the ½-lb. rocket. (See figs. 42 to 49.)

Saltpetre, pulverized	4 lbs.
Sulphur, sublimed	1 lb.
Dog-wood charcoal	1 lb. 8 oz.

The charcoal is placed on a tray lined with copper, and rolled with a gun-metal roller until it is fine enough to pass through a wire sieve, 17 meshes to the inch. The saltpetre and sulphur are put in a mixing tray, and well amalgamated with a

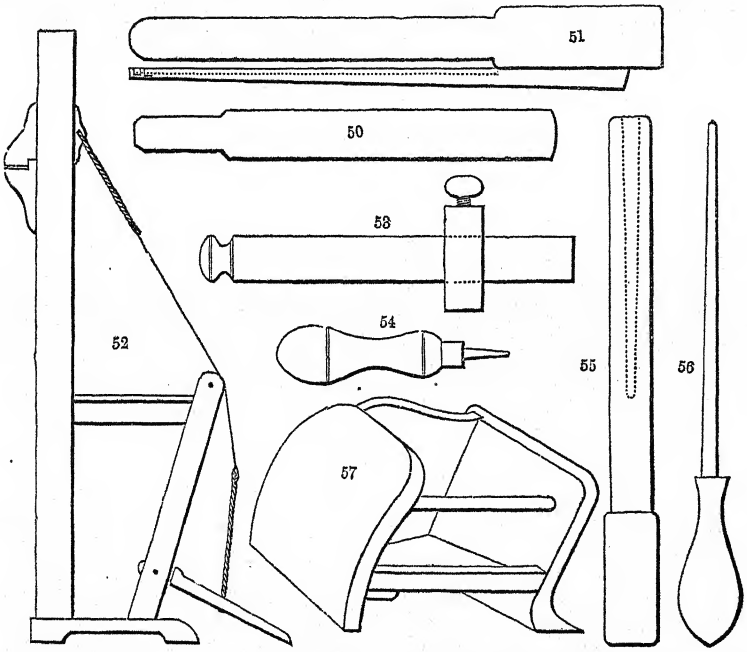


42. Brass former.
43. Cylinder-gauge.
44. Cutting stick.
45. Nipple former.
46. Nipple.
47. Setting mould.
48. Press.
49. Length-gauge.

copper slice, and then passed through a fine hair sieve. The portion of charcoal is next spread thinly over the tray, and the other ingredients sifted over it, the whole being well mixed together with the hands. It is then passed four times through the wire sieve, and any portion not passing must again be rubbed sufficiently fine to do so. It is then taken up with a copper shovel, and put into the composition box ready for use.

The slip-gauge is first put down to the bottom of the case, which is marked with a pricker through the hole in the gauge, on the exterior of the case; the diameter-gauge is then taken, and the bottom pin placed in the hole made by the pricker: the pin, being tapped with a mallet, will leave an impression on the case (the 3½ diameter mark being the length of the spindle). From the 3½ diameter to the 4½ solid,—from the 4½ solid, ½ of a diameter, clay is driven in the same way.

The setting drift is then inserted, and the case beaten with a light mallet to remove the paste from the surface, previous to moulding. The case is placed in the mould, and set on the spindle, replacing the setting drift, and giving it a few blows with the mallet. The mould is screwed tight, and the driving commenced by taking a ladleful of composition from the box, and striking it off level with the bar across the box, for the purpose. On turning it into the case, take the longest hollow drift, and with the mallet give it the regulated number of blows, viz. 25 blows for each ladleful for the 1 ℔. rocket and 21 blows for the ½ ℔. rocket, moving the drift at every blow. The driving is continued by putting in a fresh ladleful, and repeating the number of blows until the second hollow drift reaches the face of the composition, taking care, in again driving, to clear out the drift every time of putting in fresh composition. When the latter is high enough, take the next drift, and so continue until the spindle is covered, which is known by putting in a copper scoop; and if the spindle is not felt, the solid drift is taken till the composition has reached the 4½ diameter mark. If the composition is to its height, put in a ladleful of clay, and give it the same number of blows



50. Diameter-gauge.
51. Slip ditto
52. Choking frame.
53. Composition-gauge.
54. Pricker.
55. Setting drift.
56. Piercer.
57. Composition box.

as are required for the composition. For the 1 ℔. rockets, four drifts are used, and for the ½ ℔. rockets, three drifts.

The rocket is then unmoulded by loosening the screws and taking out the pin. Place the bridle on the case, turning it to the right, to prevent unscrewing the spindle: the rocket is then ready for finishing.

The paper is cut to the proper size and shape, and for the projecting heads there are two papers: one is signal-rocket paper, soaked in water and pasted. The rocket ring being placed on the former, the paper is wrapped round it, and choked with Dutch thread in the groove of the ring. The other paper, which is wrapping paper, is cut longer and pasted on, and, when dry, notched round the top to cover the stars.

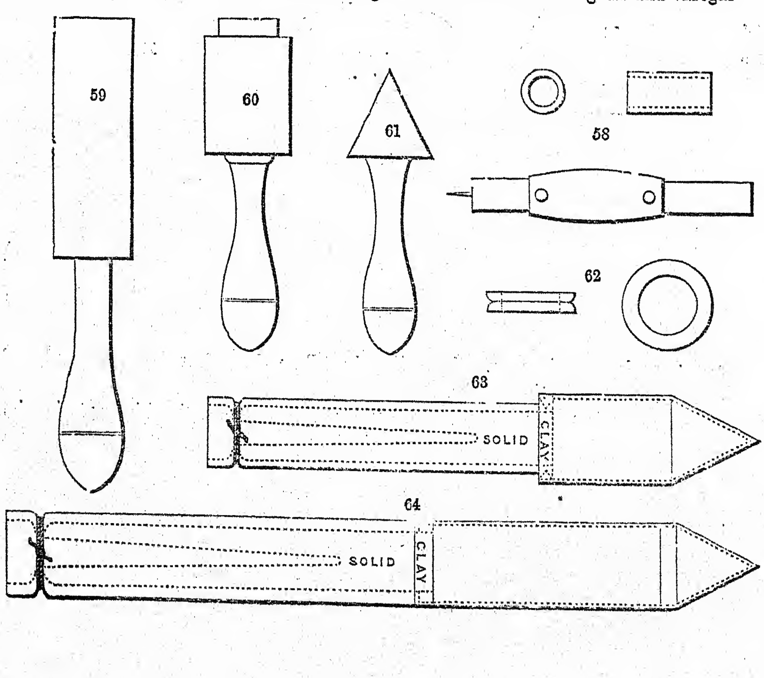
The cylinder heads are made of rocket paper, all in one piece, passing twice round the former, and having four strips cut in the part which first passes round it; then pasted and rolled, and, when dry, notched in the same way as the projecting heads. For making the cones, cut out half a circle of rocket paper, and paste it in the same manner as for the cylinders, and again a second piece over that, and notched for fixing them to the cylinders.

The cylinder gauge is put on the rocket even with the mark that denotes the height of the clay. If the rocket does not fit the gauge tight, a slip of paper is put in to make it so; then with a knife cut off what remains of the case. The gauge is then pushed down to the $4\frac{1}{2}$ diameter mark: cut off about three or four thicknesses of the paper, and peel if off until it will fit the cylinder; then with a Reimer bore a hole through the clay, up to the surface of the composition: the cylinder is then glued on. The bursting powder is next put in: 3 drs. for a 1-℔. rocket, and 2 drs. for a $\frac{1}{2}$ ℔. rocket. The stars are then placed in rows, a circle of stiff paper placed over them, and the fringe and a circle of fine paper pasted over all. The cone is then pasted on, and covered with a slip of light blue paper: it is then primed with spirits of wine and mealed powder, and is ready for service. Signal rockets for Naval Service have two coats of white paint.

Composition for making stars for signal rockets.

Saltpetre, pulverised	8 ℔s.
Sulphur, sublimed	2 ℔s.
Antimony, pounded	2 ℔s.
Cylinder-mealed Powder	1 ℔.
Isinglass	3 oz. 8 dr.
Vinegar	1 quart.
Spirits of Wine	1 pint.

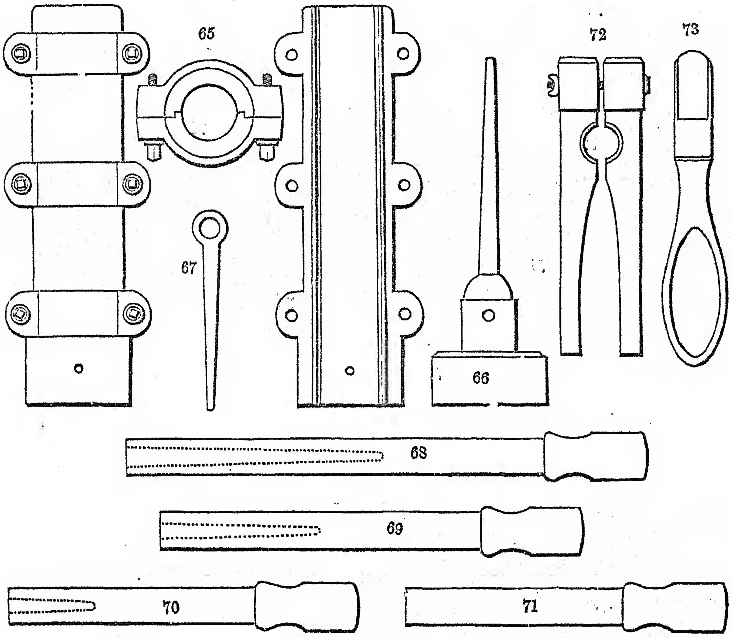
The antimony and saltpetre are first well mixed together with a slice, and when all of one colour, it is passed three times through a hair sieve. The isinglass and vinegar



58. Star mould.
59. Cylinder former for parallel heads.
60. Do. for projecting heads.
61. Cone former.
62. Ring—elevation—plan.
63. $\frac{1}{2}$lb. rocket complete.
64. 1-lb. ditto.

are put into a pot, and placed over a slow fire until all the isinglass has dissolved; the pot is then removed from the fire, and the spirits of wine added, and well stirred together with a stick. A portion of the dry composition is then put into a copper pan, and a part of the liquor also, mixing them well together till it is damp enough to adhere by the pressure of the hand. The bottom of the tray in which the stars

65. Mould.
66. Spindle.
67. Pin.
68. First hollow drift.
69. Second do.
70. Third do.
71. Solid drift.
72. Holder for drifts.
73. Ladle.



are placed is dusted with mealed powder. A portion of the composition is then laid on a board, and placing the end of the former which has the spindle into the mould, strike it into the composition, and rub the end on the board. Turn the former in the mould, and withdraw it, and insert the longest end and displace the star. The stars are then primed with mealed powder by being turned in the tray, and the powder shaken over them until all are lightly covered: they are then set aside to dry, until fit for use.

Note.—The head of a 1-lb. rocket contains 36 stars, and that of the ½-lb. rocket, 24 stars.

Tubes.

Tubes are of four different natures, viz. Common Quill and Dutch or Paper Tubes, for Exercise, and Brass, Detonating and Friction Quill, and Friction Copper Tubes, for Service.

Common quill tubes.

The quills are passed through a gauge 2-10ths of an inch in diameter, and are then rounded, with the back of a pair of scissors, on a board for the purpose. As much only of the point is cut off as will admit the drift without splitting the quill, which is cut to 3 inches in length. The quill is next placed in a spring press, and with a seven-bladed knife about half an inch from the large end is slit, and the prongs turned back with the fingers; then with a needle and worsted worked over and under each prong all round till it is large enough to form the cup, which is about 7-10ths of an inch in diameter.

Mealed powder is damped with spirits of wine in a copper pan, and the tube struck twice into the powder, and then rammed in hard with a brass drift. This is continued till the tube is filled, after which a brass piercer (No. 19 wire) is forced up the tube, and turned round at the same time, till a hole is made through the centre.

74. Spring press.
75. Slitting knife.
76. Rounding board.
77. Gauge.
78. Drift.
79. Piercer.

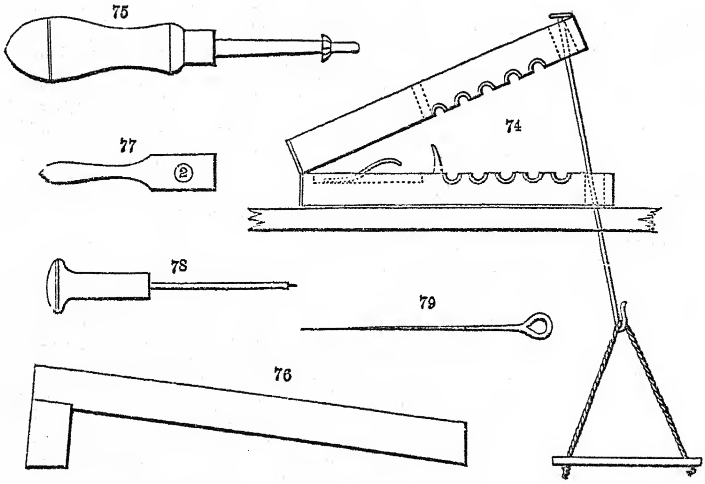
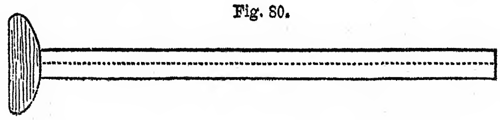


Fig. 80.



Dutch or paper ubes.

They are primed by mealed powder, damped in spirits of wine, being rubbed into the cup, which is afterwards dipped in dry mealed powder, and the tube again pierced, using No. 21 wire. They are then laid by to dry, and afterwards capped by a piece of paper being twisted over the cup.

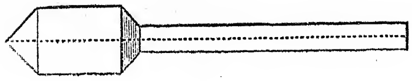
Note.—They are packed in bundles containing 100 each.

The barrels are formed of slips of whited-brown paper, 5½ inches long and 2 inches wide. These are thinly pasted over and formed on a wire former; they are then rolled between two boards, and afterwards laid by to dry. The barrels are next dry-rubbed between the same boards, to make them round, and then cut to lengths of 1¾ inch. The tube is then put on a cupping wire, and the cup formed with a slip of paper, cut 4-10ths of an inch wide and 17 inches long. The wire is held in the left hand, and the slip between the finger and thumb of the right, and laid on a board and thinly pasted; the edge of the paper is gradually raised so as to form a cup. They are then painted twice, to make them strong before being filled.

They are filled in precisely the same manner as common quill tubes.

A thick paste is made of mealed powder and spirits of wine; the piercer is put through the top of the tube, about a quarter of an inch, which is then plastered so as to form a cone. Dry mealed powder is rubbed in upon it, and a cap made of fine paper put over the cup. The cap is dipped in a solution of saltpetre, and choked under the cup.

Fig. 81.



Detonating or cross-headed tubes.

The quills of the detonating tubes are prepared in the first instance in the same manner as common tubes, but the small ends are not cut off, as in the latter. They are cut to $2\frac{3}{4}$ inches in length, and are without cups. A small hole is bored with a lathe through the quill, about 1-10th of an inch from the top of the large end. Small or pigeon quills are also prepared for the arms to receive the detonating composition. These are cut to $\frac{3}{4}$ of an inch in length (the small end is not cut), and a small hole is bored in the centre, to communicate the composition to the body of the tube.

The body of the tube is filled precisely in the same way as common tubes.

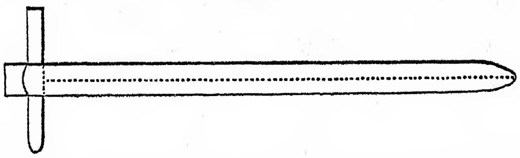
The cross or arm is filled solid with the following composition, which must be occasionally damped with spirits of wine and gum-water.

Chlorate of potassa	48 parts.
Cylinder mealed powder . . .	4 ,,
Antimony	48 ,,
Sulphur	4 ,,
Glass, finely pounded . . .	13 ,,

The cross is then placed in the holes at the top of the body of the tube, and fastened with waxed silk. The vacancy on the top of the body is filled with fine-grained powder, and plugged up with a small portion of putty. Lastly, the head of the tube is dipped into a varnish composed of shell-lac and spirits of wine.

Note.—Great care is required in mixing the above composition, as it will sometimes ignite even in mixing with a wooden slice. The antimony and glass are first

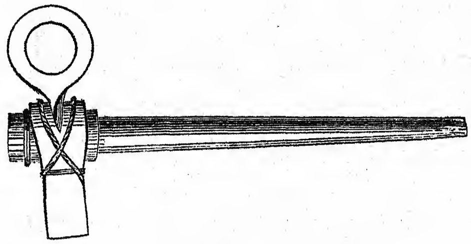
Fig. 82.



separately pounded in a mortar, and then mixed together with the chlorate, in paper, small quantities at a time.

Fig. 83.

Friction tube, quill.

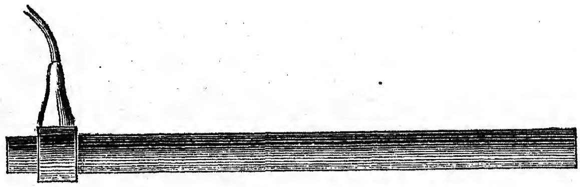


The principle of both friction tubes is the same, the body of the tube is filled as

before with mealed powder, and the upper part with a composition, which ignites in consequence of the friction produced by drawing through it a piece of rough copper firmly imbedded in it for that purpose.

Fig. 84.

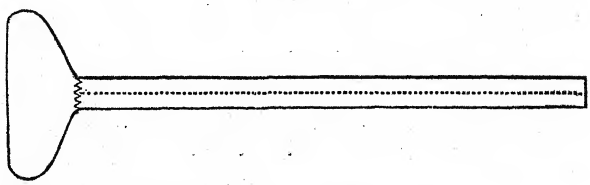
Friction tube, copper.



Brass tubes, common.

The body is formed of the same dimensions as common quill tubes, and with a cup, also of brass, to receive the priming.

Fig. 85.



They are filled precisely the same as common quill tubes.

Note.—The barrel or body of every tube is of the same diameter, viz. 2-10ths of an inch.

APPENDIX I.*

Of Fulminating Compositions used in Military Pyrotechnics.

There are but two distinct kinds of these compositions used in Military Pyrotechnics; one in which the fulminate of mercury is either the sole ingredient, or one which the composition contains. The other kind is that in which chlorate of potassa furnishes the detonating principle, and is combined with various combustibles; in one case, with fulminate of mercury.

Chlorate of potassa is not a combustible; its office is to furnish oxygen, a supporter of combustion, as is that of nitrate of potassa (saltpetre).

Both the nitrate and the chlorate of potassa furnish oxygen in equal volumes; but though the quantity of oxygen is the same in each, that in the chlorate of potassa, being combined with its base in feeble affinity compared with that in saltpetre, is readily disengaged by several means which will be noticed.

In the French and most other Artillery Services (our own excepted), fulminate of mercury is the chief ingredient in all military detonating compounds, to the exclusion of chlorate of potassa.

Musket caps in the British Service, are primed with a composition including chlorate of potassa, with the fulminate of mercury and other sensitive combustibles, besides the fulminate of mercury.†

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* By Major-Gen. Stevens, late Royal Marine Artillery.

† The detonating material for French musket caps is composed of two parts of the fulminate

Cannon tubes are primed in the detonating part with a mixture of chlorate of potassa and sulphuret of antimony.

Both of these compositions may be exploded by the direct application of fire, by heat not greatly exceeding 300 degrees, by the action of concentrated nitric and sulphuric acids, by friction, and by moderate percussive force.

In preparing fulminating compounds, numerous accidents, having serious or fatal results, have happened even to scientific men and experienced manipulators: these accidents manifest that great caution is requisite to handle any of the fulminates with safety; but though perhaps it is too much to assert that any precaution will wholly avert accidental explosions, yet a due observance of all the precautions well understood in a properly regulated Laboratory will not only reduce them to rare occurrences, but deprive them of fatal or very serious results. However, a safe and efficient knowledge and expertness of working with the sensitive materials here spoken of can only be acquired by instruction and practice in a Laboratory.

These fulminates, when exploded, generally fail to ignite gunpowder which may be lying near, or even touching them; the powder being blown to some distance by the force of the exploded fulminate, without being ignited.

This is usually accounted for by supposing the velocity of the flame of the fulminates is too great to permit sufficient heat to be communicated to the adjacent combustible; as an electric spark may be passed through a heap of gunpowder harmlessly, but which instantly explodes if the electric fire be arrested in its passage.

Cannon tubes and musket caps are the only cases in which fulminates are used in the British Service, except some signal portfires which are prepared for the Coast-Guard Service; these are primed with a mixture of chlorate of potassa and sugar: having placed on it a small glass bubble containing a drop of sulphuric acid, and hermetically closed, a thin paper is pasted over to keep this priming in its place; the portfire can then be lighted by breaking the glass bubble with any hard substance, when the mixture of the chlorate and sugar ignites and the portfire is lighted.

This ready and convenient mode of lighting is a temptation to extend an application of fulminates to blue lights, light balls, portfires, and many other military pyrotechnics; but the danger and uncertainty of the above compositions should peremptorily exclude this dangerous and unnecessary extension of their use.

There are other safe and convenient means by application of the common musket cap, which, being always at hand, obviates the necessity of fixing permanent percussion primings on signal lights and other military fire compositions. The musket cap may be fired in any manner that will bring it in contact with the priming of the composition, when ignited, as a tube somewhat resembling that used for firing rockets in the field, or a French *brûle amorce*, or even a circular plate of iron about 2 inches in diameter, having a nipple in the centre for the cap, which, being ignited by a blow of any hard substance, at once lights the fire-work if placed close down upon its priming; or if a few grains of powder are required to insure ignition, a musket-cartridge will always be at hand to furnish them. But these subtile agents are so sensitive, and their action so readily diverted or altogether arrested, by seemingly unimportant alterations, that it is not safe to affirm what will be the result of new

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of mercury and one part of pulverised saltpetre, by weight, damped with water.—*Aide-Mémoire d'Artillerie*, p. 183.

The composition for French cannon tubes is two parts of fulminate of mercury and two of mealed powder, intimately (but carefully) mixed together, then formed into a paste by means of distilled water *slightly* impregnated with gum-arabic.—*Aide-Mémoire d'Artillerie Navale*, p. 273.

applications. Little can with certainty be inferred, and each alteration should be received only when it has been abundantly tested by experiment.

In decorative and recreative fire-works, chlorate of potassa, fulminating mercury, and even more sensitive fulminates, are employed.

The brilliant purple, crimson, and green stars thrown from the heads of rockets cannot be made without either the fulminate of mercury or chlorate of potassa entering into their constituents; but these complicated though beautiful compositions are of so dangerous a nature, that no consideration should admit them into stores or magazines, or on board ships; since they are not only liable in a higher degree to the accidents pointed out, but are liable to take fire by what is termed spontaneous combustion, particularly when exposed to a hot and humid atmosphere, as several accidents from them have proved.

NOTE.—The advantages claimed for the following invention are of so important a character for modern fire-arms, that it seems only right to draw attention to it, in order that, if found correct, it may be used; and if otherwise, such alterations or improvements may be suggested as shall render the invention really valuable.—EDITOR.

PREPARATION OF GUNPOWDER FOR LOADING ORDNANCE AND SMALL ARMS.

A method has lately been patented by Captain J. H. Brown, R.N., for forming common gunpowder into a hard compact mass, so as to allow a small space of air between the grains in order to obtain greater rapidity of ignition.

In the specification the inventor gives the following explanation of the method of procedure :—

"In preparing the gunpowder I employ a solution of spirit or fluid which will not prejudicially act on the gunpowder, containing an admixture of gumaceous or adhesive matter, and deposit the same in moulds of brass, gun-metal, or other suitable material of the necessary form and size for containing the required charge, and by the application of pressure I compress it into a cake or charge. I regulate the pressure so as to bring the grains of powder into close contact, and cause them to adhere together without destroying the granulations.

* * * * * *

"The solution I prefer to employ is prepared as follows :—I take at the rate of one pound of clean picked gum arabic, and make a mucilage by dissolving it in two pounds of cold water; I also dissolve a quarter of a pound of nitrate of potash in five times its weight of cold water, which I add to the mucilage of gum arabic, and when intimately mixed I add a pound of spirits of wine, and well triturate the solution until an uniform opaque fluid is produced which is fit for use."

The advantages said to be derived from the powder being in a mass are the following :—

First, That with a breech-loader, the loose grains of powder which produce so much damage, are done away with by this means.

Second, With a muzzle-loading rifle, the grains of loose powder are apt to stick in the grooves when the rifle is a little foul, and thus the fouling is rapidly increased. With this solid powder no such evil will exist.

Third, If it be required to load a rifle when lying down, with the gun horizontal, it can be accomplished with this solid powder without difficulty.

Fourth, To the sportsman no accidents are likely to occur if this powder be used,

such as the bursting of a powder-flask in the hands, as the charge is dropped into the muzzle, and the hand immediately withdrawn.

Fifth, The solid powder can be attached to the bullet, and the two can be dropped together into the rifle, and thus great rapidity of firing is obtained.

Sixth, Experiment has shown that no priming is required, the ignition of the charge by the common cap being instantaneous. Also it is found that with the same quantity of powder a somewhat longer range is obtained by the consolidated than by the loose grained powder.

The expense will be very trifling, about five per cent. more than the common powder.

Q.

QUARRY,* so called from *quadratarius*, which, in the Latin of the lower ages, was the term applied to a stonecutter, *qui marmora quadrat;* and hence *quarry*, the place where he quadrates or cuts the stones in squares. This term was originally used to signify those places where stone for building purposes was procured, but its application has been extended to all rock excavations (except mines), for whatever purpose made. Quarries are generally opened and worked for two purposes :

First, When it is immaterial what may be the shape and size of the masses of loosened rock, as in quarries for lime, road material, &c. ; and excavations, such as the ditches of a fortress or cuttings of a railway, where the object may be to remove the stone, and not to save it for building purposes ; and

Secondly, When the rock is obtained in blocks fitted for building purposes, in shapes easily reducible to those forms which are best adapted for the designs of the architect or sculptor.

In either case, a great object in quarrying operations, as indeed in all others, is economy, or the producing the greatest results with the available means ; and for this purpose it is necessary to study closely the formation of the rock in which the excavation is to be made, in order to take advantage of those natural flaws and divisions, where they may exist, which will be found materially to lessen the labour and facilitate the operations of the quarryman. Under this head, rocks are naturally divided into stratified and unstratified. The former includes a large class of most valuable building material, such as the magnesian lime, sand and freestones, millstone grit, Yorkshire landings, &c. ; many of which can be cut or forced from their original positions without the intervention of any explosive agent. The methods in use for this purpose vary in detail, but are similar in nature. They require that a surface of the rock parallel to the bed of deposit should first be laid bare, and also that the stratum or layer from which the stone is proposed to be taken should be broken through or disconnected from the general mass, so as to allow a detached portion to be removed by sliding upon its natural bed. Having marked on the exposed surface the size of the block required, its separation is effected by driving in rows of wrought-iron wedges around it. These are at moderate intervals, depending on the facility with which the rock can be cleaved, and are struck in succession until at length the openings made by them extend from one to the other, and through the stratum : the block is then free to slide from its original position. Should the stratum be too thick and

* By Colonel Simmons, C.B., R.E.

firm to admit of a separation being effected in this way, a channel is sometimes cut, which may extend in some cases, in the form of the letter V, to a depth of two or even three feet, into it; and the wedges are then applied in the bottom of the channel. This, however, would only be done where the rock is of a nature which easily yields to the cutting tool (generally a pointed hammer, called a *pick-hammer*).

Occasionally, also, in rocks that are easily cleaved, a row of wedges is also introduced parallel to the natural cleavage, by striking which at the same time as the others which are upon the surface, the stratum can be split so that the block procured need not extend to the full thickness of the stratum. These methods apply principally to the second case, that is, when it is desired to procure blocks fitted for building or other purposes; but it behoves the Engineer, in the event of an excavation being required n a stratified rock under the first case, viz. when the masses are not required in blocks of any particular form, to ascertain how far he may make use of this system with economy, instead of adopting the method hereafter described, when an explosive agent is used. In the case of thin strata by nature, capable of being split with facility, this system may be applied under ordinary circumstances: and when the explosive agent cannot be abundantly or readily procured, it may be carried to a greater extent.

For the purposes of quarrying under other circumstances, that is, where the rock is unstratified, or of a nature not allowing it to be readily cleaved, or where the natural divisions are so far apart as to render too laborious the application of wedges, another system is adopted, by which the rock is disrupted by explosive agencies.

Two substances, gun-cotton and powder, have been used for this object; but as the former has not as yet been brought into very general use, and cannot therefore always be procured,—more especially in the Colonies, in which are executed a large proportion of the works that are intrusted to the direction of Officers of the Royal Engineers,—and as the effects of it seem to be somewhat uncertain, depending on the manner in which it is applied and the space in which it is confined, and also, in the present state of knowledge, upon its not being very safe for general application by ordinary quarrymen,—in treating of this subject, the more generally applied and better understood explosive agent, gunpowder, will only be considered, in which much assistance has been derived from an able paper on 'Blasting Rock,' written by General Sir John Burgoyne, K.C.B., and published in the fourth volume of the Professional Papers of the Corps of Royal Engineers, and also since in the form of a rudimentary treatise, by Weale, to which the reader is referred for a more extensive treatise on the subject than can be given in a work of this nature.

It is of the utmost importance to select a judicious position for the charge, with reference to the effect desired to be produced, and to the economy of the labour required to place that charge, and of the powder itself; in determining which, the following general principles will be found to apply, to which, however, sufficient attention is seldom yielded, the quarrymen being often allowed to place the charges and determine the quantities of powder according to their own notions, very often totally devoid of any definite principle.

In opening a quarry, the first object to be obtained is an exposed surface, behind which the charges being placed, they will find a less resistance than elsewhere, and will consequently force it outwards, removing the intervening matter from the principal mass. A vertical exposed surface is preferable, as being the most easy for the quarryman to place his charge behind.

Powder, when exploded, acts equally in all directions, and therefore if one part of the mass surrounding the charge be weaker, or offer less resistance than another, it

must yield to a *sufficiently* powerful charge.* The distance from the centre of the charge, or of explosion, to that point on the surface at which the elastic gases produced by the explosion find the easiest access to the atmosphere, is called *the line of least resistance.* This will be the shortest when the charge is surrounded by an uniformly resisting medium; any inequality in this respect might cause a much *longer* line than that drawn directly from the charge to the surface, to be the line of least resistance, as when a mine is imperfectly tamped, or where rock and earth surround the charge. Charges of powder, when their strength is uniform, produce effects varying with their weight; that is, a double charge will move a double mass, a treble charge a treble mass, and so on; and as homogeneous masses vary as the cube of any similar line within them, the general rule is established, that charges of powder to produce similar results are to each other as the cubes of the lines of least resistance. Hence, having determined carefully by experiment the charge to produce a given effect in a particular class of substance, the charge to produce a like result on a given mass of a similar nature is readily determined.

The variety of substances acted upon, and the very great varieties in the quality of powder, render it necessary, in the undertaking of quarrying operations, that experiments should in all cases, when they are of any extent, be instituted to determine the constant which should be employed in calculating the charges of powder.

Having determined the place of the charge, it is above all things important that the line of least resistance, as decided upon, should remain that of *least* resistance, or that the aperture by which the powder is introduced should be so secured or *tamped* as not to allow an easier vent to the elastic gases formed by the explosion than this line, which has been assumed in the calculations; also that no natural flaws or fissures should be overlooked, by which the powder may find a vent. This latter means by which the force of the explosion is sometimes lost, requires particular attention in lower geological formations, and in stratified rocks will generally determine that the line of least resistance should be perpendicular to the beds of the strata, and that the hole for the charge should be driven parallel to the strata, and so as not to touch the planes which separate them.

Various have been the methods tried for tamping these holes; but as none have been found practicable, which are as strong as the undisturbed rock, it is evident that the introduction of the charge in the direction of the line of least resistance should be avoided as much as possible, in order to save powder, as the full effect due to the powder can only then be produced by making such an increased allowance for the charge as will counterbalance the loss consequent on the diminished resistance.

Boring for Blasting.—These apertures are made by boring with iron rods called borers or jumpers, according as they are struck on their heads with a hammer or merely jumped up and down and allowed to penetrate the rock by their own weight. These are of various sizes, and have wedge-shaped pieces of steel welded to their end, called *bits*, which are brought to an edge, so as to cut into the rock. The holes may be made in almost any direction, but that which is most advantageously worked is vertical, in which case the weight of the cutting tool is brought into useful co-operation with the force employed to drive it. With the jumper it is the weight alone which produces the effect.

The speed with which holes are sunk into rock depends on the nature of the rock,

* If the mass in which the powder is placed exceed in strength its power to dislodge it, then it does not give way, but an enlargement only of the cavity in which the powder is placed occurs by the crushing to dust the parts in immediate contact with it, which receive the force of the explosion. This action is similar to that of a globe of compression.

and on the size and weight of the boring tools; it having been ascertained, from long experience, that three men are able to sink, in granite of good quality, at the following rates:

Fig. 1.

With a 3-inch jumper,	4 feet in a day.	
,, $2\frac{1}{2}$,,	5	,,
,, $2\frac{1}{4}$,,	6	,,
,, 2 ,,	8	,,
,, $1\frac{3}{4}$,,	12	,,

In working the two last classes, where the holes are not very deep, a strong boy will answer to turn the jumper. With a 1-inch jumper, a strong man bored 8 feet in a day.

In using borers it is necessary to pay some attention to the weight of hammer used for striking them. If too heavy, by fatiguing the men and reducing the number of blows given, a less effect is produced than if lighter hammers are used; and if too light, the strength of the miner is not kept fully employed in raising the hammer. The usual weight is from 5 to 7 lbs.

It therefore is evident that it is desirable to sink the holes of as small a bore as possible, considering the size of the charge, which *should in all cases* be determined by weight, and ought not to occupy too great a length in the bore-hole; the object being to get the centre of the charge as near as possible to the centre of explosion. In order to effect this object of placing a large charge at the bottom of a small hole, which is also advantageous as presenting greater facilities for tamping, various plans have been adopted. At the bottom of the bore, small charges have been placed and fired, so proportioned as not to produce fracture to the rock; they then have the effect of enlarging the space (called chamber) for another charge, which can be inserted by boring through the tamping. This operation may be repeated several times when it is desired to place a large charge at the bottom.

Another plan, applicable principally to calcareous stones, has been tried with good effect. The rock having been pierced in the usual way, a copper pipe, the size of the bore, is introduced (see fig. 1), the end A reaching to the bottom of the hole, which is closed up tight at B with clay, so that no air can escape. This pipe has a bent neck C, for a purpose hereafter to be explained. Through the copper pipe at D, a small leaden pipe is introduced, about half an inch in diameter, formed with a funnel *f* at the top, and is passed down to within about 1 inch from the bottom; the upper orifice of the copper tube round the leaden one at *g* being filled with a packing of hemp. Matters being thus adjusted, dilute nitric acid is poured through the funnel and leaden pipe, which, dissolving the calcareous rock at the bottom, causes an effervescence, and a substance containing the dissolved lime is forced out from the orifice C, the process being continued until, rom the quantity of acid consumed, it is judged that the chamber is sufficiently enlarged. Other acids, such as muriatic or sulphuric, will produce the same effect, but the result of the chemical solution will depend on the nature of the stone and the proportion of its chemical constituents.

It may be assumed that 1 lb of powder, when loosely poured but not shaken or compressed, will occupy about 30 cubic inches; or 1 cubic foot will weigh about $57\frac{1}{2}$ lbs.; consequently a hole 1 inch in diameter and 1 inch in depth will weigh ·419 of an ounce, multiplying which by the square of the diameter of the hole in inches, will give the weight of an inch in depth of powder in any given hole; whence can readily be determined either the length of hole for a given charge, or the charge in a given space.

Gunpowder varies very materially in quality, a comparison between Merchants' blasting powder and Government cannon powder giving arcs by an éprouvette gun from 12·0 to 21·0 degrees: it is therefore of very great importance that powder should be tried before purchasing or commencing to use it in quarrying, so as to prevent disappointment in the expected results, or an excessive use of powder.

The benefits resulting from the use of strong powder are evident:

1st. Smaller quantities are required, and consequently less stowage room.

2ndly. Greater effect is produced in comparison to the labour expended in boring.

3rdly. Increased resistance in the tamping, the powder occupying less space, and leaving more for the tamping.

In determining the most economic method of producing a given quantity of stone from a quarry of any particular description of rock, the following points are first to be ascertained:

1. The constant from which the charge is to be calculated.
2. The speed with which holes of different bores can be driven.
3. The effect of agents, such as small charges or acids, in enlarging chambers.
4. The face which can be established in the quarry; for it is obvious that the higher this face is, if the charge is placed behind it, the greater will be the proportional effect on the mass dislodged; the powder acting on a like mass in either instance, but leaving a much greater mass to be dislodged by its own weight in the one than in the other.

These data having being determined, and the size of the block required being known, the calculation is to be made whether large charges are to be adopted or a succession of smaller ones.

Large charges have one decided advantage, not requiring that the quarry should be so often cleared of workmen during firing.

The loading of mines in rock requires great care, to prevent accidents, the safety with which the operation is performed in a great measure depending on it. A few grains of powder loose on the side of the bore-hole may produce explosion in tamping. For the purpose of loading, the use of copper vessels is recommended.

A copper canister, with cover, to contain the powder;

A set of copper measures, containing given weights of powder (1 lb., 4 oz., and 1 oz.);

A set of cylindrical tubes, 3 feet in length, $\frac{3}{4}$ inch in diameter, which can be screwed together to form a long tube, and a copper funnel.

When the charge has been placed at the bottom of the holes by means of these instruments, a Bickford's fuze, or galvanic wires in a small bursting charge, are placed upon it, and then a wadding, after which the hole is tamped, and is ready for firing.

Bickford's fuze is strongly recommended in quarrying operations at the present time. It is not expensive, is very certain in its effects, not easily damaged in tamping, and not affected by damp. In wet situations, by enclosing the charge in a canister or water-proof bag, with a fuze attached, the firing is conducted with facility.

The galvanic battery has been used in large operations with great effect: a number of charges being placed, a simultaneous effect is certain when required. This is

found useful sometimes in moving large masses, and also where a number of men are working in a quarry, and they are withdrawn for the purpose of firing a mine : there is no uncertainty in their returning to their work, as immediately the wires are disconnected from the battery, there is no danger of explosion.

Tamping.—In tamping, the object desired is to obtain the greatest amount of resistance over the charge of powder. Different materials have been employed for this purpose.

The chips and dust of the quarry itself are very commonly used.

Sand poured in loose, or stirred up as it is poured in, to make it more compact.

Clay, well dried, either by the sun or by fire.

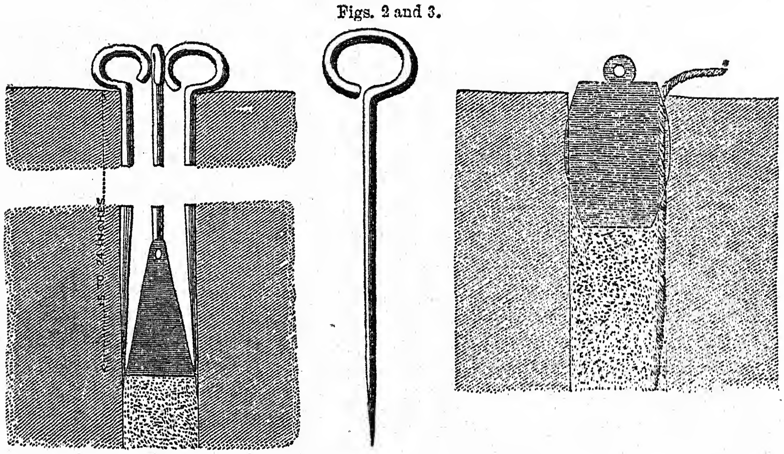
Broken brick and stone.

Various opinions have been given upon these materials ; and sand, as being easily used, very generally attainable, and offering a very great resistance from the friction of the particles among themselves and against the sides of the mine-hole, has been highly spoken of by French Engineers.

Experiments made by British Engineers have not given these favourable results, but have rather tended to give to well-dried clay the preference, as offering the greatest resistance.

Mechanical contrivances have also been used to assist the tamping : the sketches (figs. 2 and 3) shew what may be considered the best, consisting of an inverted cone,

Figs. 2 and 3.



wedged in on the tamping with arrows, or of a barrel-shaped plug ; but these would only be used in particular circumstances, when the cost and labour consequent on their use would be well repaid by the improved effect of the explosion, such as in shafts or galleries, &c.

In rock excavations for the ditches of a fortress, or for the cutting of a railway, the economy of the operation depends in a very great degree on the skill with which powder is applied in the quarrying operations. The first thing to be obtained is a gullet or small cutting, extending throughout the work, which must be carried down rather below the bottom of the ditch or cutting. This is of great importance, and that every successive widening of the gullet should be carried down to the full depth.

In some extensive railway works, involving probably the heaviest quarrying operations in Great Britain, the cutting was carried to a depth two or three feet less than

what was required of the Contractor. In taking it out, each cubic yard cost about a guinea to remove, whereas the rest of the cutting had not averaged much more than 3*s.* 6*d.* for each cubic yard.

This arose probably from neglect in the first instance, as the cutting being very deep, had the gullet been taken out to the required depth, the same quantity of powder, placed a little deeper, would have produced the effect of taking out the cutting to the required depth.

It would be wrong to conclude a subject of this nature without adverting to two of the largest explosions probably ever effected as quarrying operations; the first, in 1843, when three charges of 7500, 6500, and 5500 lbs. were simultaneously exploded by the action of three galvanic batteries, at the Round Down Cliff, near Dover, to effect a cutting for the railway. The material acted upon was chalk, the lines of least resistance 72 and 56 feet, the charge being calculated, in pounds, as $\frac{1}{32}$nd of the cube of that line in feet, with something additional to provide against contingencies.

The mass brought down from the cliff was 400,000 cubic yards, being a parallel mass or slice from the face of the cliff, 380 feet in height, 80 feet in thickness, and 360 feet in length of face.

The other occasion was in the year 1850, when two charges of 12,000 lbs. each were simultaneously exploded by the action of two distinct batteries, in a chalk cliff at Seaford, on the coast of Sussex, the object being to form a groin to arrest the progress of the shingle along the southern coast. The lines of least resistance in this case were 70 feet, and the charges were calculated on the same proportions as in the Round Down explosion and placed 120 feet apart. The operation was most successful, the mass brought down being 211 feet in height (the whole height of the cliff), about 240 on the face, by a depth of about 90 feet.

In both of these cases the force of the powder acted to blow out a crater, (the lines of least resistance being horizontal,) which bore but a small proportion to the mass dislodged. This mass was brought down principally by its own weight, having been deprived of support by the removal of the substance within the crater.

These explosions tend to establish entire confidence in the proportion of charge adopted for the material (chalk) in which they took place.

It is probable that a slight increase might be required in some descriptions of rock, but the chalk operated upon being of a very firm and homogeneous nature, and very free from fissures, would lead to the conclusion that no material would require a much greater proportion of charge.

QUARTERING OF TROOPS. See Sanitary Precautions.

R.

RAILWAY.*

Preliminary Remarks.—Facility of intercourse between different districts is so essential to the development of the prosperity of countries and to the general advancement of civilisation, that the introduction of railways will ever be looked upon as a remarkable epoch in the history of the world.

The immense benefits arising from the increased rapidity and ease of communication afforded by railways caused their speedy adoption on the Continent of Europe as well as in the United States; but they originated in England; and therefore the

* By Capt. Douglas Galton, R.E.

experience which is always required to perfect a new system has been chiefly acquired in this country, and has increased the cost of our own railways for the benefit of our neighbours. Hence, whilst the works of continental railways are constructed on principles quite as durable as ours, they have been executed at a less comparative cost. In America, however, where the feeling appears to prevail of constructing only for the present, railway works have been executed with less regard to durability and much less expensively than our own. In projecting a railway for one of our Colonies, the mode of construction to be adopted should be derived from a careful consideration of the advantages and disadvantages attendant upon each system with reference to the special circumstances of the case;—the probability also that in an imperfectly known and partly explored country, future discoveries, and the determination of the sites of towns and villages dependent on them, may require deviations in the course of a railway, should also be considered with reference to the permanency and nature of the works: it is therefore here proposed, after sketching the general principles applicable to railways in this country, to append a few remarks on the American mode of construction.

The plan of facilitating the draught of carriages by forming a hard continuous surface for the wheels to run upon is old and simple; and the successive adaptations of flagstones, pieces of wood, and iron rails to the purpose, are the several improvements it has undergone.

As early as in 1649, a wooden railway for coal was in use near Newcastle-upon Tyne, on which one horse could draw four or five chaldrons. The frequent repairs which this mode of construction required led Mr. Reynolds, of Coalbrook Dale, to substitute, in 1767, plates of cast iron; these were nailed to longitudinal sleepers, and a flange was affixed to each plate to keep the carriage in place. In this form they were known as tram-plates; and tramways, on which the plates were attached either to stone blocks or to transverse or longitudinal sleepers, were extensively used in the mineral districts of this country. This arrangement, however, which was defective because it permitted the accumulation of dirt, was at length superseded, in 1789, by an edge-rail, the flange being transferred to the wheel. Stone bearers for the rails came into use in 1800; and in 1820 Mr. Birkenshaw obtained a patent for making the rails of wrought iron.

Until 1825, railways had been almost exclusively constructed for the transport of coal, ores, slates, &c.; but in that year a company was incorporated by Act of Parliament for the purpose of making a railway from Stockton to Darlington, to convey passengers as well as goods. The Liverpool and Manchester Railway Company was incorporated in 1826, and the London and Birmingham Company in 1833, although projected some years previously. These railways, when first talked of, were intended to have been worked by horses; and so little was the present amount of traffic foreseen, that the latter railway was originally projected for one line of rails. The rapid increase of railways since 1826 has been owing to the successful substitution of steam for horse-power, and to the great improvements which have taken, and are still taking, place in the Locomotive Engine.

As far back as in 1802, Richard Trevithick took out the first patent for adapting a steam engine to move along a road, although Watt is said to have invented one previously: in 1811, Mr. Blenkinsop patented the first double-cylindered engine; it weighed 5 tons, and could draw 4 tons on a level at $3\frac{1}{2}$ miles per hour. In 1829, the Liverpool and Manchester Railway Company offered a premium of £500 for the best locomotive engine. The prize was adjudged to the 'Rocket,' designed by Mr. Robert Stephenson, weighing $7\frac{1}{2}$ tons, and able to draw 44 tons' load at 14 miles per hour on a level. The principal improvement in speed was due to the increase of

evaporating power obtained by the use of a tubular boiler. In 1838, the principle of working locomotives expansively came into use; and this, together with alterations in the valves, &c., diminished the consumption of fuel by between one quarter and one-half.

Since that period, the improvements in railways and engines have been so rapid, that it would be beyond the limits of this article to follow them.

Gauges.—The gauge of the lines at first constructed was the same as that of the tramways near Darlington, viz. 4 feet 8½ inches. The Great Western Railway Company, incorporated in 1835, adopted a gauge of 7 feet. The promoters of this increased width of gauge expected to obtain by it greater convenience and stability in the carriages, a less amount of friction, and a more roomy and therefore more powerful description of engine; whilst its opponents considered it would involve an increased expense in constructing and maintaining the permanent way, which would not be counterbalanced by the advantages to be derived from it. A Commission was appointed by Government, in 1845, to inquire into and report upon the merits of the respective gauges; and a Report upon the same subject was made, in 1848, by the Commissioners of Railways, to an order of the House of Lords. From these Reports it appears that there is not any material difference in the relative advantages of the two gauges so far as goods traffic, or traffic at low velocities, is concerned; but that the largest engines on the broad-gauge lines can draw an ordinary passenger train of 60 tons with as much facility on a level, at 60 miles per hour, as the narrow-gauge engines can at 50,—that on descending gradients they retain the advantage until considerations of safety limit the speed,—and that on ascending gradients the superiority of the broad gauge, after a certain point, will diminish as the gradients increase in steepness. The railways for which Acts were obtained after this variation of gauge had been projected, adopted the gauge of the line with which they communicated, and the break of gauge which has thus been permitted is a serious inconvenience, both in a commercial and military point of view.

It is probable that if railways had to be laid down again in England, the experience which has been acquired would cause the adoption of an intermediate gauge. This has been the case in Ireland, where the gauge has been made 5 feet 3 inches wide, on the assumption that it would allow sufficient width for the requirements of the engine without materially increasing the expenses of construction. In those Colonies, therefore, where a new system of railways has to be laid down, which can never be connected with lines already in existence, it is possible that this latter gauge might be found most advantageous.

Competing Lines.—The private Companies who first undertook to construct railways intended them to be public means of conveyance, like canals and turnpike-roads, on which any one might conduct trains of passengers or goods on paying a regulated toll; as, however, the high velocities attained required, with a view to safety, a punctual adherence to fixed hours of arrival and departure, and an implicit obedience to signals and other regulations for the safety of the traffic, it was found absolutely necessary that the general working of a line should be under the control of one head; and hence the present system has grown up of Railway Companies being carriers on, as well as possessors of, the various lines, by which means they have completely monopolised the main traffic of the country; and as long as this system obtains, there is no way of preventing it, as it is only in districts possessing an extraordinary amount of population or of traffic that parallel lines of railway could pay; and even where they could pay, competing lines would soon come to an agreement, the great outlay of capital securing them from further competition; and it might probably be more advantageous for the work to be done by one Company, provided that, were the

amount so great as to cause obstruction or danger, the Company should lay down additional lines of rails. Since, therefore, the comfort of the public is so much at the mercy of Railway Companies,—that the capital invested in railways is so large in amount as to exercise an important influence on the money-market of the country,—and that the powers which Companies obtain from Parliament are so extensive,—it has become a subject of considerable discussion how far the Government should interfere in the management, or examine the accounts, of Railway Companies. The duties of Engineer Officers in the Colonies may so frequently call upon them to consider the question of railways in a political as well as in an economical and engineering point of view, that no apology appears to be necessary for endeavouring to direct attention to the subject by the above remarks.

Legislative Enactments.—The only General Acts of consequence which have hitherto been passed concerning railways were to regulate the conveyance of mails and of troops; and one in 1845 to render all subsequent lines liable to a revision of tolls after ten years, if their dividends for the preceding three years should equal or exceed ten per cent. per annum; to compel Companies to run one train each way daily, of carriages and at times approved of by the Government, at a speed of not less than 12 miles per hour including stoppages, and at fares not exceeding 1*d.* per mile. The right of purchasing any railway at the expiration of 21 years from the passing of the Act, on repayment of the capital, is also reserved to the Government. By the terms of the Act for the conveyance of troops, Railway Companies are bound to convey Officers, with 1 cwt. of personal baggage, in first-class carriages, at 2*d.* per mile; and soldiers, with ½ cwt. of baggage, in second-class carriages, at 1*d.* per mile; and their families at similar rates. Extra baggage is liable to be charged ½*d.* per lb.; and military stores, exclusive of gunpowder, 2*d.* per ton per mile.

Objects and Advantages of Railways.—Railways may be projected either for commercial, political, or military purposes; and the judicious selection of a line will depend as much upon the merits it possesses in an engineering point of view, and the collateral advantages it embraces, as upon its fulfilling the main objects of its promoters.

A railway, except when it is intended to fulfil some political or military object, is a matter of mercantile consideration; and the expense at which it can be worked must therefore effect such a saving upon the cost of the existing means of conveyance as to afford a fair remuneration on the capital expended. When, however, a railway is once made, the advantages which the travelling public acquire from it are to a certain extent independent of the cost of construction or of working, as it is the interest of a Company to charge that fare which is expected to produce a maximum net profit; and this will increase with the facilities afforded for travelling, and, to a certain point, with the diminution of price. But, besides the advantages of cheapness and speed in travelling which the public derive from railways, they also profit by the increased rapidity and certainty in the conveyance of goods, which enables dealers residing at a distance from the main points of supply to procure the articles they require at so short a notice as not to be obliged to keep large stocks on hand; and this again releases, for other uses, capital so tied up.

The advantage of a railway to its proprietors is measure practically by the profits it yields to them; and these depend upon the original cost of construction, upon the expense of maintaining and of working the line, and upon the amount of traffic.

The capital which is expended upon the construction of a railway varies with the quantity and value of the land, the quality of the soil, the nature and geological structure of the country (which determines the amount of engineering works), and the price of labour.—The expense of working and of maintaining a line is regulated by the severity of the gradients and the cost of fuel and of labour.—And the amount

of traffic depends on the number, occupations, and habits of the inhabitants of the towns and districts through which the line passes, on their productions and requirements, and on the markets which the railway may render available to them. And since the profit to be derived from a railway depends upon the excess of the receipts from traffic over the expenses of working and maintenance, it is necessary that the line should be laid out not only with a view to the greatest economy in the cost of construction, but to possess facilities in working, to pass near towns and through populous districts, and to be of easy access.

In the following remarks it is endeavoured to shew the principal points connected—

1st. With construction,

2ndly, With working,

3rdly, With the amount of traffic to be expected upon a railway.

Construction of Railways.—Cost.—The original cost of constructing railways in this country may be classed under six heads, viz. Law and Parliamentary Expenses, Engineering, Land and Compensation, Works, Locomotive and Carrying Stock, Interest and Miscellaneous.

An average taken from fifty railways gives the total cost per mile at £34,000; but as these railways were among the earliest made, and as a diminution of expense has since taken place under some of the heads, it is probable that the present average will be considerably lower: it may, however, be assumed that the per-centage of each of the above-mentioned heads, upon the total cost of construction, is for

Law and Parliamentary Expenses	2·75
Engineering	1·75
Land and Compensation	15·00
Works	70·00
Working Stock	7·50
Interest and Miscellaneous	3·00
	100·00

The cost per mile of some few railways, selected from different parts of the country, may be interesting, when classed under the principal heads.

Name of Railways.	Land and Compensation.	Works.	Rails.	Total cost per mile.
	£.	£.	£.	£.
London and Birmingham. .	7,700	36,900	4,400	53,700
Great Western.	6,400	32,500	9,400	56,200
Birmingham and Gloucester .	3,200	14,500	3,300	24,700
London and Brighton. . .	8,800	39,300	3,600	61,000
London and Blackwall . .	113,500	98,500	4,000	253,000
Leicester and Swannington .	1,000	5,700	700	• 8,700

The amount required in this country for parliamentary expenses is comparatively large; and this is due to the system which has been adopted for the settlement of questions of this nature by the Houses of Parliament, who refer the consideration of the relative merits of the proposed lines to Committees of their own Members, instead of laying down rules for the guidance of some separate competent tribunal. Formerly there was no means of securing uniformity in the powers conferred by the Special Acts; but in 1845 the Consolidation Acts were passed, by which all the clauses

relating to taking land, raising capital, &c., were collected into two Acts (the Railway and Land Clauses Consolidation Acts), which are now incorporated with every Special Act, and from which no deviation is permitted without good cause being shewn.

Survey.—The preliminary survey required to enable Committees of the Houses of Parliament to judge of the merits of projected lines must be sufficient for the plans to shew the direction of the line, the various properties severed or affected, as well as those of which portions would require to be taken, and it extends usually to 100 yards on each side of the proposed line. A section corresponding to the upper surface of the rails is also made, on which is marked the level of the railway with respect to the surface of every turnpike-road, public carriage-road, river, canal, or railway, with the heights and spans of bridges and viaducts.

It is convenient, in the sections, to make the horizontal and vertical scale of the same denomination, the one being in chains and the other in feet: 25 to 1 inch will be found to be a good one. The plan shewing the general direction of the line is generally on a scale of 1 inch to a mile,—the plan for defining the properties on a scale of 6 inches to a mile.

The cost will probably average £50 per mile in this country. The expense of the special survey made after the Act has been obtained, including setting out the line, may be assumed at from £90 to £100 per mile.

Curves and Gradients.—A railway approaches perfection in so far as it approximates to a horizontal straight line; but questions of economy, arising from the intervention of natural and artificial obstructions, or the advantage of passing through particular districts, induce deviations in practice; and the consequent introduction of curves and gradients should be limited by considering at what point the increase in the working expenses caused by them will equal the interest on the capital saved in the construction of the line. Before proceeding further, therefore, it will be desirable to make a few remarks on the mechanical effects of curves and gradients.

Curves.—When a railway carriage moves on a curve, the resistance it meets with is due partly to the effect of centrifugal force, which causes the flange of the outer wheel to press against the rail; partly to the dragging of the wheels, which, being fixed to the axles (on account of its having been found nearly impossible to make them run true when moveable), are obliged to perform an equal number of revolutions, whether on the inner or outer rail; and partly to the axles being parallel. These causes, combined, produce great wear and tear, the exact amount of which, however, cannot be easily ascertained. The centrifugal force can be counteracted by raising the outer rail above the level of the inner one, just so much as would form the roadway into an inclined plane on which the tendency of the carriage to slide towards the centre of the curve by its own gravity, would exactly balance the tendency to leave the rails. The precise mode of estimating the elevation of the outer rail will be stated in describing the permanent way.

The resistance arising from the dragging caused by the wheels being fixed to the axles is diminished by the wheels being coned: the inclination usually adopted is from about $\frac{1}{7}$th to $\frac{1}{12}$th.

Curves having a radius of 60 chains do not materially affect the rate of speed.

Curves with a radius of less than 40 chains are considered sharp.

On the Great Western Railway, the curves are chiefly of 4, 5, and 6 miles radius. On the Bristol and Gloucester, and Edinburgh and Glasgow Railways, the average radius is 1 mile, and on the Manchester and Leeds Railway 60 chains. Small radii may be used at or near termini or junctions, &c., which are arrived at or departed from at diminished speeds.

Gradients.—The term gradient has been adopted to indicate those slight inclinations up which a load may be taken, although with diminished velocity, without assisting power, being thus distinguished from those steeper slopes termed inclined planes, where assisting power is intended to be used. The relative capacity of lines for traffic is theoretically limited by their gradients, and this will be the practical limit for goods trains on lines where the traffic is heavy; but where the traffic is so small that the engines are not obliged to exert their full power on the level, as usually is the case with passenger trains, the increased charge which steep gradients would occasion in the working expenses is of comparatively less importance. The question of the economy of making gradients depends upon whether the interest upon the capital saved by their introduction will be greater than the increased charge they will bring on the working expenses. Whilst, however, it is true that for goods traffic the effect of gradients will be to limit the load, except in cases where assistant engines are kept, and, consequently, to increase the cost of locomotive power, it must be remembered, that the disadvantage of the ascending gradient is in some degree counterbalanced by the benefit derived from the descending gradient.

The following Table has been constructed for the purpose of giving an idea of the relative advantages which different gradients would afford for goods traffic; the dimensions of the engine being assumed as follows: cylinder 16 inches diameter—length of stroke, 24 inches—diameter of wheels, 5 feet—weight of engine and tender, 32 tons—adhesion, 4480 lbs.—wheels coupled.

Inclination.	Load in tons with which the engine can maintain a speed of ten miles per hour.		Estimated cost per ton per mile of net load.			Remarks.
	Gross load in tons.	Net load in tons, exclusive of carriages.	Locomotive power.	Carriages.	Terminal charges.	
Level.	500	312	·035 *d*	The cost for the deterioration of carriages may be assumed at $\frac{1}{4}d.$ per carriage per mile, or about ·062*d.* per ton per mile.	These charges are to a great extent independent of the amount of goods conveyed, but may be assumed probably at 1*s.* per ton per mile.	The charges in this Table are not intended to include the maintenance of way, or the salaries of officers, &c., as it is only intended to give some idea of the relative effect upon goods traffic caused by different gradients.
1 in 5000	482	300	·036			
1 in 1000	398	224	·049			
1 in 500	317	190	·057			
1 in 250	249	145	·075			
1 in 200	222	127	·086			
1 in 150	187	104	·105			
1 in 100	142	73	·150			
1 in 90	132	66	·166			
1 in 80	121	59	·186			
1 in 70	105	50	·220			
1 in 60	96	43	·225			
1 in 50	83	34	·323			
1 in 40	69	24	·458			
1 in 30	53	14	·785			
1 in 20	37	3	3·666			

With passenger traffic, when the trains are comparatively light, the effect of gradients would be to diminish the speed; and the accompanying Table has been prepared for the purpose of shewing the comparative effects of different degrees of inclination.

Gradient.	Velocity in miles per hour.	Multiplier for distance in yards to give time in seconds.	REMARKS.
Level.	54	·0375	
1 in 2500	52	·0393	
1 in 1000	50·84	·0402	
1 in 750	50·06	·0409	
1 in 500	49·26	·0416	
1 in 250	46·65	·0438	
1 in 150	43·15	·0474	
1 in 120	41·31	·0495	
1 in 100	39·81	·0514	
1 in 90	39·18	·0522	
1 in 80	32·80	·0624	
1 in 70	23·60	·0856	
1 in 60	10	·2045	

The values in the preceding Table depend almost entirely upon quantities which are continually varying; hence the mode adopted has been to assume such as are most probable for the present day; and since in comparing the values of different gradients the differences alone will be looked to, the errors will be of less importance.

The following are the assumed dimensions of the engine, from which the Table has been calculated: diameter of cylinders, 16 inches—length of stroke, 21 inches—steam cut off at $\frac{5}{8}$ths of the stroke—diameter of driving-wheel, 6 feet 6 inches—weight of engine and tender, 32 tons—adhesion, 3700 lbs.—evaporating power, 200 cubic feet per hour—elasticity of steam in the boiler, 95 lbs. per square inch—pressure, 80 lbs. per square inch—load 50 tons, exclusive of engine and tender.

All gradients above 1 in 330 are considered first-class gradients. From 1 in 330 to 1 in 150 are fair working gradients.

The gradients on the London and Birmingham and Trent Valley lines are not steeper than 1 in 330; on the Dalkeith Branch of the North British Railway there is a gradient 8 miles long at 1 in 70; on the South Devon line (broad gauge) there is a gradient of 1 in 43, $2\frac{1}{2}$ miles long; and the Lickey incline on the Birmingham and Gloucester Railway is 2 miles long, at 1 in $37\frac{1}{2}$.

Laying out a Railway.—It is usual in laying out a railway to mark a centre line by stumps, for the levels, placed at intervals of 1 chain, and a spitlock for the direction, on each side of which the width required for the roadway and slopes of the cuttings and embankments is laid off: posts are also fixed in secure positions at every 10 chains along the line, as well as the crossings of roads and the ends of viaducts and tunnels, as references for the levels. In laying out curves on railways, numerous methods will readily suggest themselves, according to the circumstances in each case; as, for instance, by measuring offsets from the tangents and chords of the arcs, or by the intersections of angles from theodolites, one placed at each extremity of the curve, &c., &c.

Quantity of Land necessary.—The quantity of land required for a double line of railway will vary with the nature of the country: the actual width of the railway, including fences, is about a chain, or 8 acres per mile, and when the space for the slopes of embankments and cuttings has been added, it may be considered that the average quantity per mile is not less than 10 acres in very level country, 12 acres in ordinary country, and from 15 to 20 acres in very unequal country; and 1 acre per mile additional should be allowed for stations.

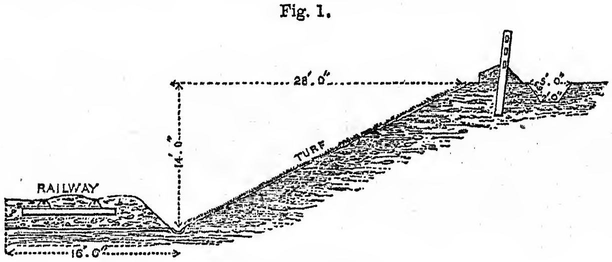
Earthworks.—The amount of earthwork, of course, depends upon the nature of the country; but an average taken from twelve railways gives 104,900 cubic yards of

excavation per mile, which may not be considered a very exorbitant amount; the excavation on the London and Brighton Railway being 156,000, and that on the Birmingham and Gloucester 79,000, cubic feet per mile.

To avoid a useless expenditure of labour, the amount of cutting should be proportioned to that of embankment; but when the quantity required in the embankment cannot be equalised with that obtained from the cutting, a convenient spot is selected for depositing the surplus, or excavating for the supply of the deficiency. When the earth from the excavation is in excess of that required for the embankment, it would perhaps in many cases be found advantageous to use the surplus in widening adjacent embankments. It is generally considered cheaper to throw to spoil than to lead three miles, though this would of course depend partly upon the height of the embankment for which side-cuttings would have to be resorted to, and partly on the facility of obtaining a site for depositing the surplus. In estimating the relative quantities, regard should be had to the nature of the soil.

Before commencing any cutting or embankment, all turf and surface soil should be carefully removed, and saved for soiling the slopes. In cuttings, the accumulation of water should be guarded against by inclining the bed of the excavation, and providing drains amply sufficient for the largest amount of water that could possibly be required to be discharged from the cutting; and all soft material in the cutting should be thrown to spoil. In some soils it may be necessary to discontinue the formation of embankments during inclement weather, as some soils will stand when deposited dry, which, if deposited wet, will always be liable to slip.

Fig. 1.



Section of Cutting.

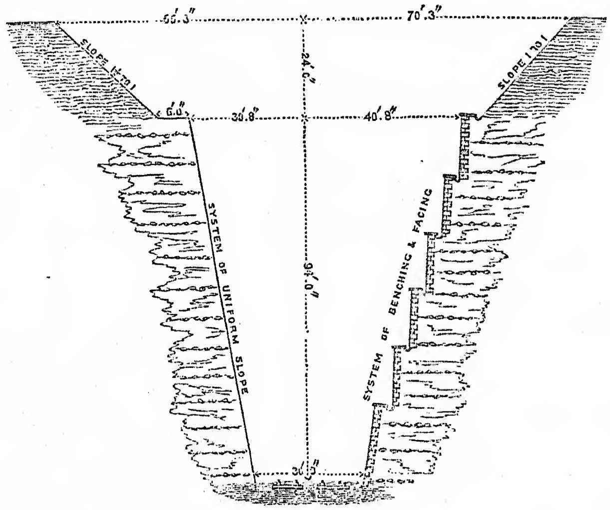
The slopes of the cuttings and embankments depend on the nature of the soil, which should be carefully ascertained by boring. In all stratified rocks, the direction and amount of the dip of the strata become important considerations in determining the form to be given to the sides of the cuttings. Other rocks stand nearly vertical. Slaty rock disintegrates when exposed to frost, but suffers less from the weather as it approaches the perpendicular, and therefore it is advisable to form the slope into steps, and cover it with vegetable mould.

Chalk varies from $\frac{1}{3}$ to 1 to 1 to 1; it frequently falls in large masses after frost or rain: layers of flint interspersed assist in maintaining the slope. In some chalks, the lower beds disintegrate much sooner than the upper one; and to obviate the inconveniences arising from this, a system of benching and facing with brickwork has been proposed, as shewn in the accompanying wood-cut.]

Coal measures stand at $1\frac{1}{2}$ to 1. Lias stands at $1\frac{1}{2}$ to 1, or 1 to 1, according as clay or limestone predominates. Clay is of so treacherous a nature that no average slope can be given for it: its trustworthiness depends on its constituent parts, and the drainage must be most carefully attended to: it has been known to vary from 1 to 1 to 10 to 1. Sand has stood at 1 to 1. On the Newcastle and Carlisle Railway there is a cutting through sand 100 feet deep, which stands at $1\frac{1}{2}$ to 1. Marl will stand at

from $1\frac{1}{4}$ to 1 to 1 to 1 ; gravel and dry soils, $1\frac{1}{2}$ to 1 ; or when the depth does not exceed 10 or 15 feet, 1 to 1 ;—dry hard shale, 1 to 1. Soapy shale will slip at a greater slope than 5 to 1.

Fig. 2.



Excavating in Chalk.

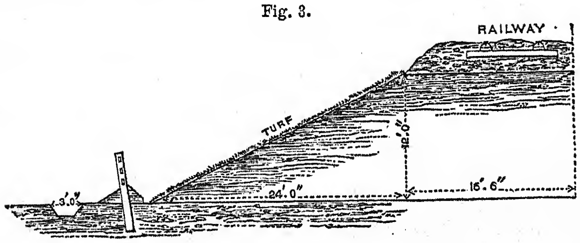
The following Table shews the angles, obtained by experiment, at which several earths stand :

Description of Earth.	Angle at which it will stand.	Name of Observer.
Earth, common, pulverised and dry	46° 50′	M. Rondelet.
Do. common, damp	54°	Do.
Do. dense and compact . . .	55°	Professor Barlow.
Flint, large	40° to 45°	Mr. G. Rennie.
Do. half the size of the above . .	35°	Do.
Do. approaching sand	34° to 35°	Do
Gravel	37°	Lieut. Hope, R.E.
Do. common	35° to 36°	Mr. G. Rennie.
Do. coarse	35° to 38°	Do.
Do. Thames, wet	35° to 36°	Do.
Mould, common	37°	Do.
Quicksand, Thames, dry	35°	Do.
Sand, fine, dry	35° 30′	Professor Barlow, M. Rondelet, and Lieut. Hope, R.E.
Do. dry	40°	Mr. G. Rennie.
Do. less dry	39° 9′	Do.
Shingle, loose, dry	39°	Major-Gen. Sir Charles Pasley, K.C.B.

In excavations, strata dipping towards the horizon are liable to be cut through and to slip. A skilful piece of engineering, with reference to this, was performed on the London and Birmingham Railway. In excavating through a hill, the strata were cut through and began to slip ; so the Engineer immediately caused a tunnel to be turned, and allowed the earth to slide over the top. Alternating strata of clay and sand require effectual draining. In marshy soil, a new artificial bed must sometimes

be formed by replacing the spongy soil with harder materials. In sidelong ground, it often becomes necessary to form steps for a foundation.

Fig. 3.

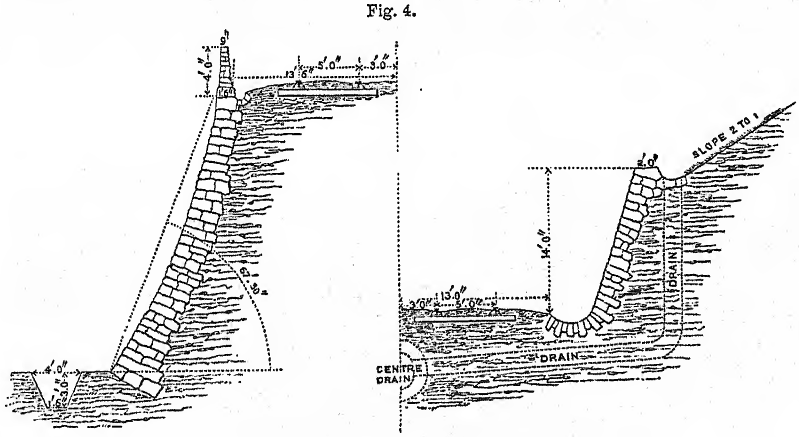


Section of an Embankment.

During the construction and after the completion of earthworks, the main cause of slips is the presence of water, either from springs or otherwise, which must be carried off by drains; the subsoil also should be drained, either by a drain under the centre of the roadway or by side ditches. In wet seasons, all soils require the greatest caution.

Gravel and sand are the best materials for embankments, as they consolidate rapidly and are easily drained. Shaly earth, when hard and dry, is also good. Dry clay mixed with straw, though long in consolidating, forms sometimes a sound embankment. Vegetable mould, soft shaly earth, wet clay and peat, are unfavourable. In crossing Chat Moss, which is of peat, Mr. Stephenson formed the embankment of the moss itself, dried. In cases of very deep bogs, in Ireland, Sir John Macneill has used for a foundation a raft formed of layers of young trees, crossing each other. It is generally considered advisable, in embankments, not to make the base of the slope less than twice its height; and when stone is plentiful or land dear, a revetment wall may be advantageously substituted for a slope.

Fig. 4.



Section of an Embankment. Section of a Cutting.

When the levels of the line and the slopes for the cuttings and embankments have been determined on, the cubic content of earthwork must be calculated; for which purpose numerous Tables have been constructed. The following, framed by H. Law, Esq., C. E., and published in 1845, are concise, and applicable to all descriptions of excavation. (*For the method of using these Tables, see p.* 214.)

TABLE I.

	LENGTH IN CHAINS.									
	1	2	3	4	5	6	7	8	9	
1	1·222	2·444	3·667	4·389	6·111	7·333	8·556	9·778	11·00	1
2	2·444	4·889	7·333	9·778	12·22	14·67	17·11	19·56	22·00	2
3	3·667	7·333	11·00	14·67	18·33	22·00	25·67	29·33	33·00	3
4	4·889	9·778	14·67	19·56	24·44	29·33	34·22	39·11	44·00	4
5	6·111	12·22	18·33	24·44	30·56	36·67	42·78	48·89	55·00	5
6	7·333	14·67	22·00	29·33	36·67	44·00	51·33	58·67	66·00	6
7	8·556	17·11	25·67	34·22	42·78	51·33	59·89	68·44	77·00	7
8	9·778	19·56	29·33	39·11	48·89	58·67	68·44	78·22	88·00	8
9	11·00	22·00	33·00	44·00	55·00	66·00	77·00	88·00	99·00	9
10	12·22	24·44	36·67	48·89	61·11	73·33	85·56	97·78	110·0	10
	1	2	3	4	5	6	7	8	9	
11	13·44	26·89	40·33	53·78	67·22	80·67	94·11	107·6	121·0	11
12	14·67	29·33	44·00	58·67	73·33	88·00	102·7	117·3	132·0	12
13	15·89	31·78	47·67	63·56	79·44	95·33	111·2	127·1	143·0	13
14	17·11	34·22	51·33	68·44	85·56	102·7	119·8	136·9	154·0	14
15	18·33	36·67	55·00	73·33	91·67	110·0	123·3	146·7	165·0	15
16	19·56	39·11	58·67	78·22	97·78	117·3	136·9	156·4	176·0	16
17	20·78	41·56	62·33	83·11	103·9	124·7	145·4	166·2	187·0	17
18	22·00	44·00	66·00	88·00	110·0	132·0	154·0	176·0	198·0	18
19	23·22	46·44	69·67	92·89	116·1	139·3	162·6	185·8	209·0	19
20	24·44	48·89	73·33	97·78	122·2	146·7	171·1	195·6	220·0	20
	1	2	3	4	5	6	7	8	9	
21	25·67	51·33	77·00	102·7	128·3	154·0	179·7	205·3	231·0	21
22	26·89	53·78	80·67	107·6	134·4	161·3	188·2	215·1	242·0	22
23	28·11	56·22	84·33	112·4	140·6	168·7	196·8	224·9	253·0	23
24	29·33	58·67	88·00	117·3	146·7	176·0	205·3	234·7	264·0	24
25	30·56	61·11	91·67	122·2	152·8	183·3	213·9	244·4	275·0	25
26	31·78	63·56	95·33	127·1	158·9	190·7	222·4	254·2	286·0	26
27	33·00	66·00	99·00	132·0	165·0	198·0	231·0	264·0	297·0	27
28	34·22	68·44	102·7	136·9	171·1	205·3	239·6	273·7	308·0	28
29	35·44	70·89	106·3	141·8	177·2	212·7	248·1	283·6	319·0	29
30	36·67	73·33	110·0	146·7	183·3	220·0	256·7	293·3	330·0	30

	LENGTH IN CHAINS.									
	1	2	3	4	5	6	7	8	9	
31	37·89	75·78	113·7	151·6	189·4	227·3	265·2	303·1	341·0	31
32	39·11	78·22	117·3	156·4	195·6	234·7	273·8	312·9	352·0	32
33	40·33	80·67	121·0	161·3	201·7	242·0	282·3	322·7	363·0	33
34	41·56	83·11	124·7	166·2	207·8	249·3	290·9	332·4	374·0	34
35	42·78	85·56	128·3	171·1	213·9	256·7	299·4	342·2	385·0	35
36	44·00	88·00	132·0	176·0	220·0	264·0	308·0	352·0	396·0	36
37	45·22	90·44	135·7	180·9	226·1	271·3	316·6	361·8	407·0	37
38	46·44	92·89	139·3	185·8	232·2	278·7	325·1	371·6	418·0	38
39	47·67	95·33	143·0	190·7	238·3	286·0	333·7	381·3	429·0	39
40	48·89	97·78	146·7	195·6	244·4	293·3	342·2	391·1	440·0	40
	1	2	3	4	5	6	7	8	9	
41	50·11	100·2	150·3	200·4	250·6	300·7	350·8	400·9	451·0	41
42	51·33	102·7	154·0	205·3	256·7	308·0	359·3	410·7	462·0	42
43	52·56	105·1	157·7	210·2	262·8	315·3	367·9	420·4	473·0	43
44	53·78	107·6	161·3	215·1	268·9	322·7	376·4	430·2	484·0	44
45	55·00	110·0	165 0	220·0	275·0	330·0	385·0	440·0	495·0	45
46	56·22	112·4	168·7	224·9	281·1	337·3	393·6	449·8	506·0	46
47	57·44	114·9	172·3	229·8	287·2	344·7	402·1	459·6	517·0	47
48	58·67	117·3	176·0	234·7	293·3	352·0	410·7	469·3	528·0	48
49	59·89	119·8	179·7	239·6	299·4	359·3	419·2	479·1	539·0	49
50	61·11	122·2	183·3	244·4	305·6	366·6	427·8	488·9	550·0	50
	1	2	3	4	5	6	7	8	9	
51	62·33	124·7	187·0	249·3	311·7	374·0	436·3	498·7	561·0	51
52	63·56	127·1	190·7	254·2	317·8	381·3	444·9	508·4	572·0	52
53	64·78	129·6	194·3	259·1	323·9	388·7	453·4	518·2	583·0	53
54	66·00	132·0	198·0	264·0	330·0	396·0	462·0	528·0	594·0	54
55	67·22	134·4	201·7	268·9	336·1	403·3	470·6	537·8	605·0	55
56	68·44	136·9	205·3	273·8	342·2	410·7	479·1	547·6	616·0	56
57	69·67	139·3	209·0	278·7	348·3	418·0	487·7	557·3	627·0	57
58	70·89	141·8	212·7	283·6	354·4	425·3	496·2	567·1	638·0	58
59	72·11	144·2	216·3	288·4	360·6	432·7	504·8	576·9	649·0	59
60	73·33	146·7	220·0	293·3	366·7	440·0	513·3	586·7	660·0	60

TABLE I.—(CONTINUED.)

	LENGTH IN CHAINS.									
	1	2	3	4	5	6	7	8	9	
61	74·56	149·1	223·7	298·2	372·8	447·3	521·9	596·4	671·0	61
62	75·78	151·6	227·3	303·1	378·9	454·7	530·4	606·2	682·0	62
63	77·00	154·0	231·0	308·0	385·0	462·0	539·0	616·0	693·0	63
64	78·22	156·4	234·7	312·9	391·1	469·3	547·6	625·8	794·0	64
65	79·44	158·9	238·3	317·8	397·2	476·7	556·1	635·6	715·0	65
66	80·67	161·3	242·0	322·7	403·3	484·0	564·7	645·3	726·0	66
67	81·89	163·8	245·7	327·6	409·4	491·3	573·2	655·1	737·0	67
68	83·11	166·2	249·3	332·4	415·6	498·7	581·8	664·9	748·0	68
69	84·33	168·7	253·0	337·3	421·7	506·0	590·3	674·7	759·0	69
70	85·56	171·1	256·7	342·2	427·8	513·3	598·9	684·4	770·0	70
	1	2	3	4	5	6	7	8	9	
71	86·78	173·6	260·3	347·1	433·9	520·7	607·4	694·2	781·0	71
72	88·00	176·0	264·0	352·0	440·0	528·0	616·0	704·0	792·0	72
73	89·22	178·4	267·7	356·9	446·1	535·3	624·6	713·8	803·0	73
74	90·44	180·9	271·3	361·8	452·2	542·7	633·1	723·6	814·0	74
75	91·67	183·3	275·0	366·7	458·3	550·0	641·7	733·3	825·0	75
76	92·89	185·8	278·7	371·6	464·4	557·3	650·2	743·1	836·0	76
77	94·11	188·2	282·3	376·4	470·6	564·7	658·8	752·9	847·0	77
78	95·33	190·7	286·0	381·3	476·7	572·0	667·3	762·7	858·0	78
79	96·56	193·1	289·7	386·2	482·8	579·3	675·9	772·4	869·0	79
80	97·78	195·6	293·3	391·1	488·9	586·7	684·4	782·2	880·0	80

	LENGTH IN CHAINS.									
	1	2	3	4	5	6	7	8	9	
81	99·00	198·0	297·0	396·0	495·0	594·0	693·0	792·0	891·0	81
82	100·2	200·4	300·7	400·9	501·1	601·3	701·6	801·8	902·0	82
83	101·4	202·9	304·3	405·8	507·2	608·7	710·1	811·6	913·0	83
84	102·7	205·3	308·0	410·7	513·3	616·0	718·7	821·3	924·0	84
85	103·9	207·8	311·7	415·6	519·4	623·3	727·2	831·1	935·0	85
86	105·1	210·2	315·3	420·4	525·6	630·7	735·3	840·9	946·0	86
87	106·3	212·7	319·0	425·3	531·7	638·0	744·3	850·7	957·0	87
88	107·6	215·1	322·7	430·2	537·8	645·3	752·9	860·4	968·0	88
89	108·8	217·6	326·3	435·1	543·9	652·7	761·4	870·2	979·0	89
90	110·0	220·0	330·0	440·0	550·0	660·0	770·0	880·0	990·0	90
	1	2	3	4	5	6	7	8	9	
91	111·2	222·4	333·7	444·9	556·1	667·3	778·6	889·8	1001	91
92	112·4	224·9	337·3	449·8	562·2	674·7	787·1	899·6	1012	92
93	113·7	227·3	341·0	454·7	568·3	682·0	795·7	909·3	1023	93
94	114·9	229·8	344·7	459·6	574·4	689·3	804·2	919·1	1034	94
95	116·1	232·2	348·3	464·4	580·6	696·7	812·8	928·9	1045	95
96	117·3	234·7	352·0	469·3	586·7	704·0	821·3	938·7	1056	96
97	118·6	237·1	355·7	474·2	592·8	711·3	829·9	948·4	1067	97
98	119·8	239·6	359·3	479·1	598·9	718·7	838·4	958·2	1078	98
99	121·0	242·0	363·0	484·0	605·0	726·0	847·0	968·0	1089	99
100	122·2	244·4	366·7	488·9	611·1	733·3	855·6	977·8	1100	100

TABLE II.

	LENGTH IN CHAINS.									
	1	2	3	4	5	6	7	8	9	
1	·4074	·8148	1·222	1·630	2·037	2·444	2·852	3·259	3·667	1
2	1·630	3·259	4·889	6·518	8·148	9·778	11·41	13·04	14·67	2
3	3·667	7·333	11·00	14·67	18·33	22·00	25·67	29·33	33·00	3
4	6·518	13·04	19·56	26·07	32·59	39·11	45·63	52·15	58·67	4
5	10·18	20·37	30·56	40·74	50·92	61·11	71·29	81·48	91·67	5
6	14·67	29·33	44·00	58·67	73·33	88·00	102·7	117·3	132·0	6
7	19·96	39·93	59·89	79·85	99·81	119·8	139·7	159·7	179·7	7
8	26·07	52·15	78·22	104·3	130·4	156·4	182·5	208·6	234·7	8
9	33·00	66·00	99·00	132·0	165·0	198·0	231·0	264·0	297·0	9
10	40·74	81·48	122·2	163·0	203·7	244·4	285·2	325·9	366·7	10

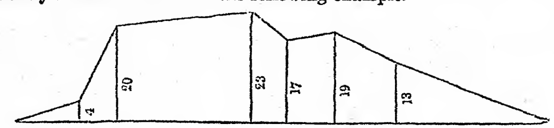
	LENGTH IN CHAINS.									
	1	2	3	4	5	6	7	8	9	
11	49·29	98·59	147·9	197·2	246·5	295·8	345·1	394·3	443·7	11
12	58·67	117·3	176·0	234·7	293·3	352·0	410·7	469·3	528·0	12
13	68·85	137·7	206·6	275·4	344·3	413·1	482·0	550·8	619·7	13
14	79·86	159·7	239·6	319·4	399·3	479·1	559·0	638·8	718·7	14
15	91·67	183·3	275·0	366·7	458·3	550·0	641·7	733·3	825·0	15
16	104·3	208·6	312·9	417·2	521·5	625·8	730·1	834·4	938·7	16
17	117·7	235·5	353·2	471·0	588·7	706·4	824·2	941·9	1060	17
18	132·0	264·0	396·0	528·0	660·0	792·0	924·0	1056	1188	18
19	147·1	294·1	441·2	588·3	735·4	882·4	1029	1177	1324	19
20	163·0	325·9	488·9	651·8	814·8	977·8	1141	1304	1467	20

TABLE II.—(CONTINUED.)

LENGTH IN CHAINS.

	1	2	3	4	5	6	7	8	9	
21	179·7	359·3	539·0	718·7	898·3	1078	1258	1437	1617	21
22	197·2	394·4	591·6	788·7	985·9	1183	1380	1577	1775	22
23	215·5	431·0	646·6	862·0	1078	1293	1509	1724	1940	23
24	234·7	469·3	704·0	938·7	1173	1408	1643	1877	2112	24
25	254·6	509·2	763·9	1018	1273	1527	1782	2037	2292	25
26	275·4	550·8	826·2	1102	1377	1652	1928	2203	2479	26
27	297·0	594·0	891·0	1188	1485	1782	2079	2376	2673	27
28	319·4	638·8	958·2	1278	1597	1916	2236	2555	2875	28
29	342·6	685·3	1028	1370	1713	2056	2398	2741	3084	29
30	366.7	733·3	1100	1467	1833	2200	2567	2933	3300	30
	1	2	3	4	5	6	7	8	9	
31	391·6	783·1	1175	1566	1958	2349	2741	3132	3524	31
32	417·2	834·4	1252	1669	2086	2503	2920	3337	3755	32
33	443·7	887·3	1331	1775	2218	2662	3106	3549	3993	33
34	471·0	941·9	1413	1884	2355	2826	3297	3768	4239	34
35	490·1	998·1	1497	1996	2495	2994	3494	3993	4492	35
36	528·0	1056	1584	2112	2640	3168	3696	4224	4752	36
37	557·7	1115	1673	2231	2789	3346	3904	4462	5020	37
38	588·3	1177	1765	2353	2941	3530	4118	4706	5295	38
39	619·7	1239	1859	2479	3098	3718	4338	4957	5577	39
40	651·8	1304	1956	2607	3259	3911	4563	5215	5867	40
	1	2	3	4	5	6	7	8	9	
41	684·9	1370	2055	2739	3424	4109	4794	5479	6164	41
42	718·7	1437	2156	2875	3593	4312	5031	5749	6468	42
43	753·3	1507	2260	3013	3766	4520	5273	6026	6780	43
44	788·7	1577	2366	3155	3944	4732	5521	6311	7099	44
45	825·0	1650	2475	3300	4125	4950	5775	6600	7425	45
46	862·1	1724	2586	3448	4310	5172	6034	6897	7759	46
47	900·0	1800	2700	3600	4500	5400	6300	7200	8100	47
48	938·7	1877	2816	3755	4693	5632	6571	7509	8448	48
49	978·2	1956	2935	3913	4891	5869	6847	7825	8804	49
50	1018	2037	3056	4074	5092	6111	7129	8148	9167	50

Note.—The method of using the Tables will be rendered perfectly clear by an examination of the following example.



7 × 4 × 14 × 3 × 5 × 6 × 18

Width of the line 30 feet. Slopes $1\frac{1}{2}$ to 1.

L	H	h	Content of trunk from Table I.	H×h	Content of one slope. (a) From Table I.	(b) From Table II.
Chains.	Feet.	Feet.	Cubic yds.		Cubic yds.	Cubic yds
7	4	—	34·2	—	——	45·6
4	20	4	117·3	80	391	417·2
10 4	23	20	525·6 210·2	460	5622 2249	36·7 14·7
3	23	17	146·7	391	1430 3	44·0
5	19	17	220·0	323	1956 18	8·1
6	19	13	234·7	247	1760 51	88·0
10 8	13	—	158·9 127·1	—	——	688·5 550·8
			1774·7		13480	1893·6
			30		1893·6	
			53241		15373·6	
			46120·8		3	
Total Contents			99361·8		46120·8	

METHOD OF USING THE TABLES.

For the Trunk or Central Part in a Cutting or Embankment.—Add together the height in feet of the two ends; then look for this No. in the first column of Table I., and on the same line, under the proper length in chains, will be found the content in cubic yards. Should the length exceed 9 chains, the content must be taken out in two operations. The content thus obtained is for 1 foot only in width; the total quantity must be multiplied by the true width in feet.

For the Slopes on the Side of a Cutting or Embankment.—If the embankment has a height at only one end, the content in cubic yards is given at once in Table II.; the height in feet being contained in the outside vertical columns.

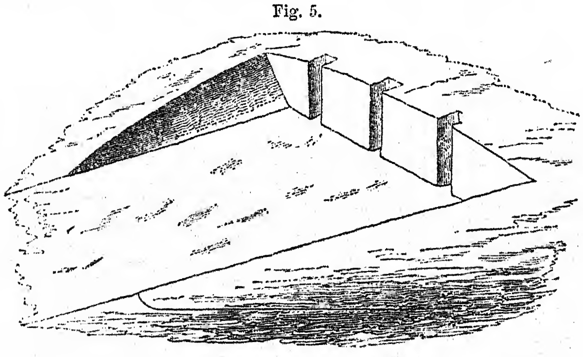
If the embankment has a height at each end, multiply the two heights together; look for this No. in the outside column of Table I., and make out the No. on the same line under the proper length (a). Then subtract the lesser height from the greater: look for this No. in the first column of Table II., and take out the No. on the same line under the proper length (b). These two (a and b) added together will give the content in cubic yards for any length not exceeding 9 chains: when greater than that, it must be taken out in two operations. The content thus obtained is for one side only, calculated upon a slope of 1 to 1: the total quantity must be doubled; and for any other slope must be multiplied by the ratio of the base to the height.

If the lengths are in feet instead of chains, these Tables may equally well be used, by taking the figures in the top line as feet, and dividing the total result by 66. (*See example, p.* 214.)

The main art of directing earthworks consists in so proportioning the men to each task, and disposing the *matériel* or plant, that none shall for a moment stand idle, and that a free passage shall be continually kept open. These proportions depend upon local circumstances, and can scarcely even approximately be made the subject of calculation, but, together with the disposition of the men, depend on the judgment of the Engineer.

Cuttings.—In commencing an excavation, a face at right angles to the direction of cutting should be obtained, and a gullet, of about 15 feet wide, formed as soon as possible. The accompanying sketch shews a mode of cutting nitches with the pick-axe, and a very little labour enables the excavator to separate the masses between.

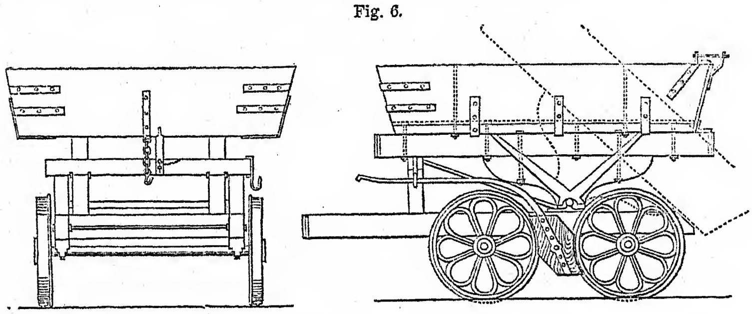
Fig. 5.



Into the gullet, when formed, a train of waggons to receive the earth is sent. As the height of the hill increases, side tracks on a higher level are laid down, and the inclines which connect them with the first line serve to enable the loaded carriages to draw up the empty ones. Plate XVIII. shews the above-described method.

Embankments.—The ordinary mode of embanking is to run out to the full height required at once, but the operation may be carried on with equal if not greater rapidity by forming a bank of half the required height, and following this up closely with an upper bank to the full height, just so much narrower as will allow waggons to pass to the head of the lower one. The most expensive, but at the same time the most solid, mode is to form the bank in successive shallow layers, each being run out and allowed to consolidate before the one above is commenced. Plate XXIX. shews the arrangements which may be adopted for leading the waggons to the head of the embankment, and the accompanying sketch (fig. 6) shews a front and side elevation of a waggon.

Fig. 6.



It may be assumed that at the average rate of wages of the present day, and with contract work conducted as efficiently as it is in this country, the following prices will give a fair idea of the cost of earthwork, viz:

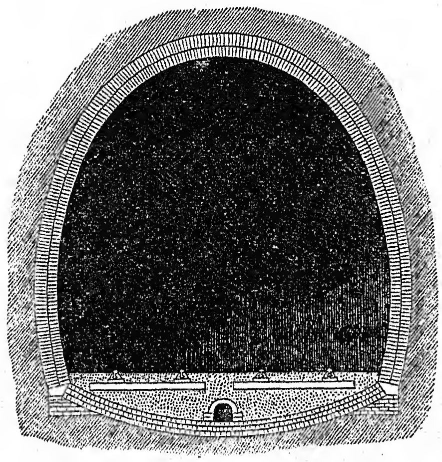
	Average. s.	d.
Excavating, carrying, and forming into embankment, with any lead not exceeding half a mile, not rock . from 9*d.* to 1*s.* 3*d.* per cubic yard,	1	$0\frac{1}{2}$
Do., do., hard close rock . . . . from 1*s.* to 4*s.* do. do.	2	$4\frac{1}{2}$
Excavation from tunnel, all plant being found by the contractor, from 5*s.* to 7*s.* do. do.	6	2
If the lead exceeds half a mile, the following would be the addition to the price, according to the distance, for every fractional part of a mile: at the rate per mile of . . . . from 4*d* to 8*d.* do. do.	0	$5\frac{1}{4}$
Turfing, soiling, and sowing slopes (including cost of stripping and setting aside, such not being paid for in the earthwork), 10 inches thick, from 2*d.* to 8*d.* per sq. yard,	0	$4\frac{1}{4}$
Metalling surface of new roads . . . . from 1*s.* to 3*s.* do. do.	1	$11\frac{1}{2}$
Metalling surface of temporary divisions, including contingencies, from 1*s.* to 2*s.* do. do.	1	7

Temporary fencing, from 1*s.* 6*d.* to 2*s.* per foot run.

Tunnel.—The advantage of substituting a tunnel for a cutting, or a viaduct for an embankment, will depend chiefly on local circumstances, as the surplus or deficiency of the material excavated, the price of land, and the geological formation of the country. (See fig. 7.)

The expense of a tunnel will depend upon the strata through which it is to be carried, and on the absence or presence of water: as this circumstance can seldom be foreseen, it is almost impossible to form a correct estimate, but careful borings, previous to commencing the work, will be found very useful.

Fig. 7.



Section of Tunnel, showing Drainage.

The following prices shew how much they vary in expense, viz.

Name of Tunnel.	Price per yard.	
Birkenhead Tunnel (single line)	£32	in red sandstone.
Box Tunnel, on Great Western,	100	,, oolitic rock
Bletchingley, South-Eastern	72	
Cheltenham	34	
Clay Cross, North-Midland	100	
Grovely Hill, Bristol and Birmingham	32	,, marl
Kilsby, London and North-Western	125	
Leeds, Leeds and Selby	25	,, shale & coal measures
Lime Street, Liverpool	80	,, red sandstone
Royston, North-Midland	50	,, red sandstone
Saltwood, South-Eastern	118	
Summit, Manchester and Leeds	97	
Whiteball, Exeter	53	

The expense of the Kilsby and Saltwood tunnels was increased by meeting with large quantities of water.

It may be mentioned here, that in tunnelling through chalk, '*pot holes*,' are frequently met with, which are cylindrical shafts, worn apparently by the rotatory action of water and stones, and filled generally with gravel or some other foreign substance; and the removal of the chalk from below the bottom of these, leaving only a thin shell to support them, frequently causes their contents to break through, and occasionally to do serious damage to the tunnel.

Viaducts.—In the construction of viaducts, either instead of embankments or to carry a railway over roads, rivers, &c., Engineers appear to concur in considering that brick and stone are the most desirable materials to use; but questions of economy, and the necessity of crossing large spans with a level soffit, often compel them to adopt wood and iron: and where the foundations are treacherous, as in the mining districts, or where the substrata are compressible, a flat soffit affords capabilities for repair which are highly advantageous.

Although it does not properly fall within the present limits to describe the numerous varieties in the modes of construction of bridges to which the rapid extension of railways has given rise, it does appear desirable to state the effect which velocity has on bridges subject to deflection in increasing the strain due to a given weight.

Effects of Velocity on Bridges subject to Deflection.—If a weight be laid upon a beam supported at each end by props, it will produce a deflection; this deflection will be greatest at or near the centre, but the greatest curvature will occur at the point where the weight is suspended. If the weight be made to traverse the beam with rapidity, it may be conceived that an additional effect due to the motion of the body in a curve will be produced, and that the re-action of the beam would be the resultant of this additional force, which would act in the direction of the radius of curvature and of the force of gravity. This re-action of the beam may be resolved into two forces, one acting in the direction of the tangent to the beam, the other at right angles to it; and this latter force would represent the tendency of the bar to break. It will, upon consideration, be evident that the additional effect above mentioned will vary directly with the square of the velocity and the deflection, and inversely with the length of the beam. The mathematical investigation of this question is extremely complicated. The following is a short sketch of the mode of solution adopted by Professor Willis and Professor Stokes, and given at full length in the Appendix to the Report of the Commissioners for inquiring into the Application of Iron to Railway Structures.

It may be deduced, from what previous writers on the strength of materials have said, that if a weight be suspended from a beam (the inertia of the beam being neglected, and the weight considered as a heavy moving point), and if the deflection at the point of suspension $=y$, and the distance of the point from the end of the bar $=x$, the half-length of the bar $=a$, and the weight suspended $=\mathrm{W}$; then $y=c\,\mathrm{W}\,(2\,a\,x-x^2)^2$, when c is a constant quantity dependent upon the elasticity and transverse section of the bar. Now if M be the mass of the weight, S the central statical deflection, or deflection produced by the weight when at rest, and R the re-action between the body and the bar (which, as the deflection is small, may be supposed to act vertically), the elastic re-action of the bar at any point (its inertia being neglected) is equal to the weight which, when suspended at that point, would depress it to the same distance below the horizontal line. Therefore, $\mathrm{R}=\mathrm{W}=\frac{y}{c}\cdot\frac{1}{(2\,a\,x-x^2)^2}$; and if $x=l$, or half the length of the bar, y becomes equal to S; and if $\mathrm{R}=\mathrm{M}g$ (when g represents the force of gravity), $c=\frac{\mathrm{S}}{\mathrm{M}\,g.\,a^4}$. Now if the weight be supposed to move with a velocity $=\mathrm{V}$, the forces which act on the body are its gravity and the re-action of the bar. Whence is obtained the equation of motion,

$$\frac{d^2y}{d\,t^2}=g-\frac{g\,a^4}{\mathrm{S}}\cdot\frac{y}{(2\,a\,x-x^2)^2};$$

which, since $\mathrm{V}=\frac{d\,x}{d\,t}$, becomes

$$\frac{d^2y}{d\,x^2}=\frac{g}{\mathrm{V}^2}-\frac{g\,a^4}{\mathrm{V}^2\mathrm{S}}\cdot\frac{y}{(2\,a\,x-x^2)^2}.$$

The integration of this equation would give the form of the path of the body. But it cannot apparently be integrated in finite terms, except for an infinite number of particular values of a certain constant involved in it. This constant has been termed β, and $\beta=\frac{g\,a^2}{4\,\mathrm{V}^2\mathrm{S}}$; a small value therefore corresponds to a short bridge and

a high velocity, and a large value to a long bridge and a lower velocity. If we put $g=32\cdot2$ feet, $l=$ length of bridge in feet, $V=$ velocity in feet per second, and $S=$ central statical deflection in inches, we shall have

$$\beta=24\cdot15\frac{l^2}{V^2S}.$$

When β is large, the following series will express the ratio of the central deflection due to the moving weight$=D$, to the central statical reflection $=S$.

$$\frac{D}{S}=1+\frac{1}{\beta}+\frac{5}{2\beta^2}+\frac{13}{\beta^3}+\quad\ldots$$

When β is equal to, or greater than 100, the first two terms of the series will be true to the third place of decimals; substituting therefore the value of β we obtain $D=S+\frac{4V^2\ S^2}{g\ a^2}$. Hence, for a given load, the increment of deflection due to velocity varies nearly directly as the square of the velocity, and inversely as the square of the length of the bridge. But this is on the supposition that the mass of the bridge is insignificant.

When the *inertia* is taken into account, the problem becomes so complicated that its complete solution seems to elude the present powers of analysis. It appears, however, that when β is less than about unity, the *inertia* will diminish the central deflection due to the moving weight. When β is greater than unity, the *inertia* will at first increase the deflection, and bring it to a maximum, and then diminish it. An appropriate solution of this problem has been obtained by Mr. Stokes, for the two extreme cases in which the mass of the body or mass of the bridge are neglected; and although in the cases similar to those in practice, where the masses are very nearly equal, the effects are so mixed up together as not to be as yet fully developed, the following Table, which has been calculated empirically, will serve to shew roughly the increments of statical deflection due to different conditions of bridges, until further experiments and a perfected theory shall have determined the question more exactly.

In the following Table, l=length of bridge in feet, V=velocity of moving weight in feet per second, S=central statical deflection, or deflection due to the weight at rest on the centre.

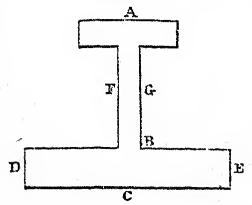
Values of $24\cdot15\,\frac{l^2}{V^2S}$.	5	6	8	10	15	20	25	30	40	50	100	200
Increments of S when mass of bar is neglected.	·30	·23	·18	·14	·10	·06	·05	·04	·03	·02	·01	·005
Increments due to the inertia.	·25	·22	·19	·17	·14	·12	·11	·10	·09	·08	·05	·04
Total increments of statical deflection.	·55	·45	·37	·31	·24	·18	·16	·14	·12	·10	·06	·045

To apply this Table to any given bridge, the statical deflection due to the greatest load which is liable to pass over it must be ascertained, and also the greatest probable velocity: from these data, and from the length of the bridge, the value of $\frac{l^2}{V^2S}$ must be calculated. The increment of statical deflection which corresponds

to this value will be found in the lower line of the Table; and since for small deflections the strain may be considered to increase with the deflection, the greatest load to which the bridge could be practically exposed should be diminished in the proportion of the total increment of statical deflection in the Table.

Strength of Iron.—The cheapest and most prevalent description of iron bridges in use upon railways is the simple cast-iron girder bridge, and the form usually adopted is that recommended by Mr. Hodgkinson, the top and bottom flanges being made parallel for convenience, and the sectional area of the bottom flange being made from four to six times greater than that of the top, on the assumption that the strength of cast iron to resist a tensile force is less than its strength to resist a crushing force in that proportion; and the breaking weight may be calculated from the following formula, where W = breaking weight in the middle of the beam, l = distance between the supports, in feet, a = area of section of bottom flange in the middle, d = depth of beam in the middle,—

Fig. 8.



$$W = \frac{2{\cdot}166\, a\, d}{l};$$

or, the effect of the vertical part between the flanges is included, and d = A C = whole depth, d' = A B = depth to bottom flange, b = D E = breadth of the bottom flange, b' = F G = thickness of the vertical part,

$$W = \frac{2}{3\, b\, d\, l}\left\{ b\, d^3 - (b - b')\, d'^3 \right\}.$$

The following formulæ, expressing the relation between the extension and compression of cast iron, and the weight producing them respectively, are given in the Report of the Commission on the Application of Iron to Railway Structures, viz.

$$\text{For extension,} \quad w = 13934040\frac{e}{l} - 2097432000\frac{e^2}{l^2},$$

$$\text{For compression,} \quad w = 12931560\frac{d}{l} - 522979200\frac{d^2}{l^2},$$

where w = weight per square inch of section, l = length of bar in inches, e = extension in inches, d = compression in inches.

Formulæ have, however, been derived by Mr. Tredgold from the same experiments, which appear to be more convenient in calculating the strength of beams, from the consideration of the forces of extension and compression acting round the neutral axis: the formulæ are—

$$\text{For extension,} \quad w = \frac{14173080\, e}{l + 288{\cdot}84\, e},$$

$$\text{For compression,} \quad w = \frac{13002840 d}{l + 51{\cdot}6\, d}.$$

The mean tensile strength of cast iron is 15711lbs. per square inch, and the ultimate extension $\frac{1}{600}$ of the length: this weight would compress a bar of cast iron of the same section $\frac{1}{775}$ of its length. The general ratio of the power of cast iron to resist tension to that to resist compression is 1 : 5·6603. In wrought iron the extensions and compressions with equal weights are nearly equal, and a rod will extend ·01124 inch for each foot in length with a weight of 11 tons per square inch. Up to this weight the extension may be assumed to vary nearly with the weights; but

beyond it the elasticity is considerably injured. Cast iron is decreased in length by compression about double the amount that wrought iron is with equal weights, whilst the ultimate strength of cast iron to resist compression is twice or three times as great as that of wrought iron. Cast iron will not bear reiterated flexure due to more than ⅓rd of its breaking weight; and on account of the concussions to which it is exposed in railway bridges, it is considered that the ultimate strength of cast-iron girders should be equal to three times the permanent load, and six times the greatest moving load that could come upon the bridge. Judging from the structures of the most eminent Engineers, it would appear that they consider 5 tons per square inch as the greatest strain to which wrought iron should be permanently exposed in railway bridges. The strength of plates of wrought iron, when compressed to resist buckling, will vary nearly as the cube of their thickness up to about 9 tons per square inch; beyond this the metal becomes injured, and the increase of strength will be more nearly in proportion to the thickness. Riveting, when executed in the best manner, will reduce the tensile strength of wrought-iron plates to about ⅔rds. Long-continued impact on riveted tubes, producing a deflection of less than one-fifth of what would be required to injure the tube by pressure, was shewn by Mr. Hodgkinson's experiments to be totally destructive to the riveting.

Bridges.—The dimensions for bridges over roads will of course be regulated by the nature of the traffic upon them: in this country, unless other sizes are provided by the Special Act, the Railway Clauses Consolidation Act allows the following minimum dimensions, viz. For a turnpike-road, the height from the ground to the springing of the arch, 12 feet; height to the crown of the arch, 16 feet; span, 35 feet: for a public carriage-road the height must be 15 feet to the crown of the arch, and the span 25 feet; and for a private carriage-road the height must be 15 feet; and the span 12 feet. By the same Act, the steepness of the approaches to bridges is also regulated, viz., the greatest slope for a turnpike-road is 1 in 30; for a public carriage-road, 1 in 20; and for a private carriage-road, 1 in 16. It should, however, be remembered that whilst a moderate incline would be very severely felt where the adjacent roads are level, in hilly country it would scarcely be perceived.*

The average cost of bridges, including the approaches, in this country, may be roughly assumed at—for turnpike-roads £2000 each; for public carriage-roads, from £1000 to £1500; and for farm or occupation roads, from £300 to £500 each.

The following list of prices for buildings, &c., may be considered as an approximate average of the cost in this country:

	Average. £	s.	d.
Masonry—of fitted rubble set in mortar, including all erections, centering, scaffolding, excavation of foundations, backing, and all contingent work necessary in the construction of tunnels, ... from 25*s.* to 45*s.* per cubic yard,	1	13	0
Ditto —arches, spandril walls, or parapet of culverts, or any other work not exceeding 2 feet in thickness, from 16*s.* to 25*s.* do. do.	0	19	0
Ditto —retaining walls, wing walls, and abutments, and all work exceeding 2 feet in thickness, ... do. do.	1	2	0
Ditto —of common rubble in boundary walls, from 10*s.* to 14*s.* do. do.	0	12	0
Brickwork—set in mortar, including all erections, centering, scaffolding, excavation of foundations, backing, and all contingent work necessary in the construction of tunnels, from 28*s.* to 32*s.* do. do.	1	10	0

* Tables shewing the ratio in which the quantities of materials for bridges increase with the increase of height are given in the article 'Passage of Rivers,' p. 69.

	Average. £ s. d.
Brickwork—arches, spandril walls, or parapets, or in culverts, or all work not exceeding $2\frac{1}{2}$ bricks in thickness, from 17*s.* 6*d.* to 35*s.* per cubic yard,	1 4 0
Ditto —retaining walls, wing walls, and abutments, and all work exceeding $2\frac{1}{2}$ feet in thickness, . . from 14*s.* to 30*s.* do. do.	1 0 0
Addition to above, if set in Roman cement, . from 5*s.* to 10*s.* do. do.	0 7 6
Ditto ditto for tunnel, from 2*s.* to 7*s.* do. do.	0 4 6
Coping of brick, set in cement, . . from 1*s.* 6*d.* to 2*s.* per cubic foot,	0 1 9
Block stone in courses, set, ... do. do.	0 1 6
Coping string-courses in stone, dressed and set, 2*s.* to 3*s.* 6*d.* do. do.	0 3 0
Ashlar, ditto ditto . . . . do. do.	0 3 4
Concrete, including excavation, . . from 6*s.* to 10*s.* per cubic yard,	0 8 0
Timber-work—fir-framed, creosoted, carried and fixed in place, including pile-driving and all contingencies, from 3*s.* 3*d.* to 5*s.* do. do.	0 3 6
Wrought iron—fixed and painted, . . . from £18 to £38, do. do.	27 0 0
Cast iron—fixed and painted, . . . from £10 to £17 10*s.* do. do.	12 0 0

Level-Crossings.—Safety requires that level crossings should be used as rarely as possible. When unavoidable, the line should be visible for some distance on each side, and a policeman or gate-keeper should be stationed at every crossing of a public road. In some cases, particularly where persons on the crossing cannot command a good view, or where the crossing is approached by a steep gradient on the railway, signals should be introduced. The average cost of a level crossing, with gates and a porter's lodge, is £450; a paved crossing, with gates for an occupation-road, will average £40. (See Plate III.)

The number of communications per mile across railways, taken from an average of 1200 miles, selected from different parts of the country, is 3·31, classed as follows: bridges over the railway, ·9 per mile; bridges under the railway, ·96; level-crossings, 1·45.

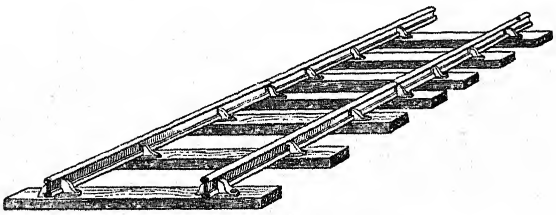
Draining.—It is essential that the slopes and revetment walls of cuttings be well drained, as also the roadway. (See Plates I. II.) Water should be prevented from accumulating, and wherever it is known to exist, its immediate source should be traced, for it is to the neglect of this precaution that most failures of works can be attributed. In solid earth or rock, good ditches will suffice for the side drains; but where depth is required, or where the earth is soft or wet, the sides must be revetted. The expense of culverts may be supposed to average £400 per mile.

Formation.—The width of the formation varies from 28 to 31 feet, and the centre is usually raised from 3 inches to 6 inches above the sides, for the sake of drainage.

Permanent Way.—The permanent way comprises the ballasting with the rails and their supports; in fact, all between the formation and rail level. The ballast should be generally not less than 18 inches in thickness between the formation level and the sleepers carrying the rails, but this depth varies with the nature of the substratum on which it is placed; its use being, in bad soil, to produce a distribution of the rolling weight over a larger surface than that immediately beneath the sleeper, and to keep the latter dry. For this surpose, the formation should have been first carefully formed with side ditches, and sloping from the centre towards both sides. Too much attention cannot be devoted to this subject, as much of the permanent cost of working depends upon the goodness or otherwise of the permanent way, one principal element in the maintenance of which is a well-drained substratum upon which it may rest.

Rails.—Rails, as laid at present, may be classified under two general forms, the requirements of which are somewhat different according to the means of support adopted. The double-headed rail, modifications of which are shown in Plates IV. V., has been generally used upon bearings at varying distances formed by sleepers 9 feet long, with a section of *not less* than about 30 square inches: between each of these sleepers the rail forms a bridge upon which the wheels travel. In this case the rail requires such a depth and section that the passing weights shall produce no

Fig. 9.

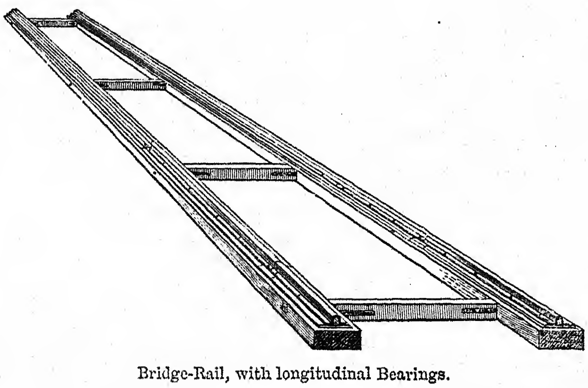


Edge-Rail, with transverse Sleepers.

great deflection, even though by an inequality in the road, or other cause, the weight of a pair of wheels be thrown upon one rail, and an occasional bearing be absent or defective. The weight, according to present practice, to be provided against may be taken as 5 tons upon one wheel, so that 10 tons should not produce a great deflection at a double distance or interval. It is obvious that, in every description of permanent way, the joint of the rail must be the weakest point, as far as the rail itself is concerned, and will require therefore to be specially strengthened by artificial means. In the transverse sleeper road, these means are provided by shortening the bearings, or bringing the sleepers nearer to each other as they approach the joints, and by placing larger sleepers or chairs under the joints, and by connecting adjacent rails at the joints by fish plates, or bracket chairs, or some other means.

The other class of rail in general use is known under the name of the bridge-rail, being of the form shown in Plate VI. It is usually placed upon longitudinal sleepers or bearers, which have a continuous bearing upon the ballast, and therefore it does not require to be so strong and stiff as that used with supports having intervals or spaces

Fig. 10.



Bridge-Rail, with longitudinal Bearings.

between them. The sleeper and rail in this case form a joint beam, and under the supposition that they are everywhere adequately supported, no strain is brought upon them beyond the mere crushing force of the rolling weight. This, however, cannot well be the case in practice, as no perfectly incompressible substance can be placed under the sleepers; and hence the effect of the rolling weight is at length to permit a small depression throughout the whole length of the rail, which causes the wheel, as it were, to be always working against an ascending or curved incline. In this description of permanent way, the timber sleepers are generally 14" × 7" in section, breaking joint with the rails and with the sleepers of the opposite rails, and they are kept apart and in proper relative position as to cant by cross timbers or transoms notched in between them at every 10 or 15 feet (the shorter distance applies to curves), to which straps of iron are bolted, the bolts passing through the sleepers, and being fixed by nuts and washers on the outside to prevent the rails from spreading. The rails are fastened to the longitudinal bearers by bolts passing through both, having large-headed fanged nuts on the under side, the fangs or prongs serving to hold the nut firmly to the timber, and short plates of wrought iron are placed under the joints, to prevent them from working into the timber. By this it will be seen, that supposing the rails to be 16 feet in length, and the gauge or width between the rails 4 feet 8½ inches, there will under each line of railway, for a single length of rail, be an area bearing upon the ballast of 37 feet, requiring about 22½ cubic feet of timber.

Supposing the transverse sleepers to be adopted, five in number to each length of rail, and 9 feet in length, in order to afford an equal bearing upon the ballast, they should be 10 inches wide; and taking them at 6 inches in depth, which is the least that should be adopted, 18¾ cubic feet will be required for 16 feet of railway: this is under the supposition that the whole of each sleeper bears upon the ballast, which in practice is never found to be the case, as the plate-layers usually pack up the ends of the sleepers and leave the middle untouched. Now, from what has been before stated, the bridge-rail does not require to be so stiff and strong as the rail upon supports at intervals, and it may be assumed, that a rail weighing 60lbs. per yard, upon the former is as effective as one weighing 70 or 75lbs. upon the latter; and again, the latter requires cast-iron chairs for seating it upon the sleepers, which generally average about one-third the weight of the rail, with a slight addition in weight to the chair which contains the joints of the rails; so that, as regards the expense of material, it appears that upon a gauge of 4 feet 8½ inches, the rail upon continuous bearings is cheaper than that upon supports at intervals. As regards efficiency, the question between the two systems admits of some doubt: the continuous bearing is probably more difficult of removal in case of decay, and its maintenance is troublesome. Upon the stability and condition of the permanent way depends in a great measure the expense of the working of the railway. Inequalities in the road may be considered as synonymous with increase of power, in proportion to weight moved, with reduction in speed when like weights are moved, and in both cases increased wear and tear upon the moving stock; and in proportion as the moving weights become unsteady, the difficulty and consequent expense of properly maintaining the road increases, each acting upon the other in a direct proportion. It is evident, therefore, that the solidity and good construction of the permanent way are of the first importance; and to establish it, the following points are those principally to be attended to:

1st. The draining of the *formation* surface.

2ndly. The nature of the ballast, which should be easily permeable by water, and at the same time have a sufficiency of fine materials to bind it together to a certain

extent.* It should not be of so light a nature as to produce dust, or to be easily raised by the current produced by passing trains, or by wind, and so get into the working parts of the engine or the axle-boxes of the carriages, and also incommode travellers. When broken stone can be obtained, it may be considered to form the best ballast, provided a few inches of gravel or very small stone be laid between it and the timber.

3rdly. The smoothness of the joints of the rails, to effect which care should be taken that the rails are square-butted and well seated on the chairs or longitudinal timbers, and so fixed that, in expanding and contracting from the effects of temperature, the intervals between the rails shall not much vary: these intervals are often increased in the case of transverse sleepers by the effect of the traffic passing always in one direction and drawing the rail in the direction of motion. The perfection of a permanent way is for every part to be alike in solidity and smoothness; and for this purpose the attention of the Engineer should be especially directed to the joints, which are naturally the weakest points in the rails. When railways were first commenced, machinery not being so perfect as it is at present, it was found impracticable to obtain rails of sufficient weight of greater lengths than 15 or 16 feet; but by improvements in the process of manufacture they may now be procured of nearly double that length. It is therefore advisable, in determining the rails for a railway, to ascertain to what lengths rails of the required weight can be rolled, and to adopt those of the greatest length, even at an increased cost, as the joints or weak parts decrease in the ratio of the length of each rail, and there is a corresponding reduction in the means to be applied to stiffen the joints, and in the labour necessary to maintain them. In the comparison of the two systems, it should not be omitted that until the introduction of the fished joint the continuous bearing had a *decided* superiority over the ordinary transverse sleeper road, by dispensing with the cast-iron chairs, which often break, with the oak keys used to fasten the rail in the chair: these keys, by the effect of the atmosphere (damp expanding and dry hot weather contracting them), are constantly varying even in the same day from tight to loose, and *vice versâ*, and are acted upon by the friction of the rail, which, in expanding, contracting, and deflecting, tends to move them, so that they are a constant source of anxiety, and require to be examined *daily* at least once, and, where there is a night traffic, twice. It is a very common thing for the key of the joint chair to work clear of the joint, and so leave the rail at that point without lateral support, which must be highly dangerous to passing trains. But the fished joint and other improved means of securing the joints lately introduced have raised the transverse sleeper road to a level with the other.

* The following rates may be assumed as the approximate cost of ballasting in this country:

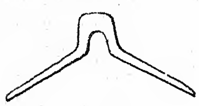
		Average per cubic yard. *s.*	*d.*
Excavating, carrying, depositing, and spreading material for ballast, from	1*s.* 6*d.* to 3*s.*	2	1½
If obtained from the necessary excavation of permanent cutting, and paid for once as earthwork, and with a lead not exceeding half a mile		2	0
Broken stones or coarse ballast	from 1*s.* 6*d.* to 3*s.*	2	2½
Burnt clay	from 2*s.* 6*d.* to 4*s.* 6*d.*	3	6
Gravel or other fine ballast	from 1*s.* 2*d.* to 2*s.*	1	7
If obtained from side cuttings or elsewhere, and not otherwise paid for as earthwork:			
Broken stone for coarse ballast	from 2*s.* to 3*s.*	2	6
Burnt clay	from 3*s.* to 4*s.* 6*d.*	3	9
Gravel or other fine ballast	from 1*s.* 6*d.* to 2*s.* 6*d.*	2	0
If the lead exceeds half a mile, addition to the prices named, according to the increase of distance for any fractional part of a mile, at the rate per mile of	from 4*d.* to 8*d.*	0	5¼

The danger apprehended from the use of the chair and key has induced the introduction, on the Irish railways, by an eminent Engineer, of a system combining the two, the bridge-rail being spiked directly to transverse sleepers, by which means the chair is dispensed with.

Other Engineers have endeavoured to combine the two systems by placing transverse sleepers under the continuous or longitudinal bearers. This system appears fallacious, for practically the two are never equally packed, and so the longitudinal bearer and rail become a combined beam to support the rolling weight over the space between the transverse supports, which are in fact the piers of a series of small bridges; and unless the spans are small, this combined girder is found not to be sufficiently rigid.

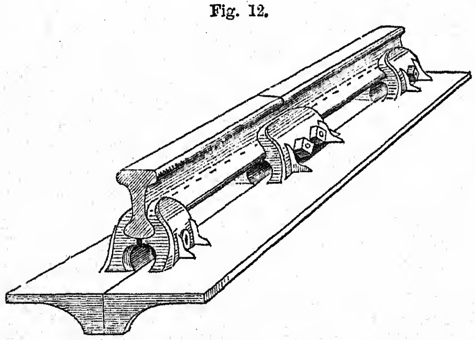
To remedy the defects of existing permanent ways, and remove the perishable material, timber, which is found to be a costly item in the working expenses of railways, various schemes have been proposed, more especially of late: but as their respective merits have not yet been fully tested, it would be premature in this place to describe them. The above principles will, however, apply in considering them, which it is strongly recommended should be carefully done by any person about to commence an extensive work of this nature. The system patented by Mr. W. H. Barlow, Engineer to the Midland Railway Company, appears to afford the greatest promise of success as applied to a new line; in it the bridge-rail is extended to a width of about 15 inches, the bottom inclining downwards from the centre, as shown in the accompanying figure, to prevent the ballast from spreading. It is proposed to make the joints by an iron chair of large dimensions and ties of broad wrought iron. This road is however found to be very hard, and easily knocked to pieces.

Fig. 11.



A cast-iron longitudinal sleeper, with chairs attached, has also been proposed, and it appears likely to be useful in enabling old lines to get their existing rails worn out without a constant expense for the removal of timber. The latter item has, however, been very much increased to them by sufficient care not having been taken in the selection of the timber in the first instance; and the defects in the timber, by allowing inequalities to arise in the roadway, have caused the rails to wear out much more rapidly than they otherwise would have done. In considering all the various systems of permanent way, it behoves Engineers in future to profit by the experience which has been already acquired, and, upon the facts to be adduced therefrom, either to adopt the best, or by combination and invention to produce a more perfect road.

Fig. 12.



Qualities of Iron.—Under the head of permanent way, it appears necessary to draw attention to the manufacture of iron, as the quality of the metal is found to differ very materially; but as this is a subject in itself, those points only will be alluded to which require particular notice, and are *desiderata* in the manufacture of rails.

1st. Rails should not be of too *short* or *brittle* a nature.

2ndly. They should present a hard surface to the passing wheels.

3rdly. The pile should be carefully made to combine the last desideratum with a power to resist crushing or disintegration at the welds formed near the upper surface in rolling; or, in other words, they should not be liable to lamination.

4thly. The ends should be square-butted.

5thly. The rail should be straight, even, and uniform.

To ascertain, as far as possible, on obtaining rails, that due attention in their manufacture has been bestowed upon them, it would appear desirable to select a certain proportion, and after having gauged them by templates and weighed them, to obtain their deflections under dead pressure, and their power to resist fracture by impact.

The weight to which rails can be rolled is limited only by the power of rolling the iron fibrous and sound: they have been rolled to more than 100lbs. per yard. No accurate average of the wear and tear due either to the passage of trains or to the weather has been published; but the destruction of the rail is generally due to lamination. To guard against this, it has lately been proposed to harden the upper surface of the rails and render the lower flange fibrous, by adding a small proportion of tin in the first case, and of calamine in the second, to the iron in the puddling furnace.

In laying the permanent way of a railway in those positions where it passes round curves, it is considered advisable, in order to diminish the resistance, to lay the rails slightly wide in gauge, to the extent of probably a quarter of an inch, and by raising the outside rail to counteract the centrifugal force consequent upon the movement of the train in a curve. To estimate the amount of this, if v' represent the velocity of the carriage in feet per second, and r' represent the radius of the curve in feet, the effect due to the centrifugal force will be $\frac{v'^2}{2r'}$; and if $x =$ the super-elevation of the outer rail, and $w =$ width of gauge (expressed in the same denomination as the super-elevation), which, as x is small, may be assumed equal to the length of the inclined plane formed by super-elevating the outer rail,—then, since a body would fall 16·1 feet in a second by gravity alone, $16{\cdot}1\frac{x}{w} =$ tendency of the body to slide down the inclined plane by which the centrifugal force is to be counteracted.

Therefore, to determine the super-elevation of the outer rail,

$$\frac{x}{w} \times 16{\cdot}1 = \frac{v'^2}{2r'} \text{ or } x = \frac{w\,v'^2}{32{\cdot}2r'};$$

and if $v =$ velocity in miles per hour,
and $r =$ radius of curve in chains,

we shall obtain $x = \frac{v^2}{1000\,r}w$, nearly.

Hence the super-elevation of the outer rail increases directly with the width of gauge and the square of the velocity, and inversely with the radius of curvature; and, theoretically, the limit to which it can be carried appears to be the point at which packages in goods carriages moving at low velocities would not be liable to displacement. When the super-elevation of the outer rail is great, and must be attained gradually, the curvature at each point should be proportioned to the elevation, and this would form a curve approaching to a parabola. If, instead of considering the rails laid down in a curve, each rail be looked upon as the side of a polygon inscribed

in a circle whose radius is the radius of curvature, as is generally the case in practice with rails when first laid, different conditions will ensue; but it is found that by use the rails soon assume the form of a curve.

Practically, the limit to which the super-elevation of the outer rail can be carried, is about 4 inches on the narrow, and 6 inches on the broad gauge, and the elevation of the rail is commenced on the tangent before the curve is entered upon. The distances usually allowed between the lines of rails in a double railway is 6 feet, which amply provides for the security of carriages and trucks of the construction in *ordinary* use on railways in England.

Points and Switches.—In order to pass from one line of rails to another, cross-over roads are introduced (see Plates V. VII.): these should in all cases be placed near stations, in order that the points may be under the surveillance of trustworthy persons, if possible the signal-men,—as indeed should be all points: a drawing of Wild's patent point or switch, apparently combining all the advantages of those in general use, is given in Plate V.

Points should in double lines be placed so that trains in passing over them, in the right direction of the traffic on the line on which they are moving, cannot leave their line without backing, either to pass into a siding, or into the opposite line of way. This remark does not apply to junctions or even to principal sidings, on lines of very heavy and continuous traffic, where the intervals between the trains are very short, and where the obstruction produced by stopping a train and moving it backwards to get into a siding or on to another line of rails, may produce risk of a collision. This latter, however, is a case that can only rarely occur, and almost exclusively in situations where, from the inclination of the railway, it becomes necessary to move the train backwards, or *shunt* against the gradient.

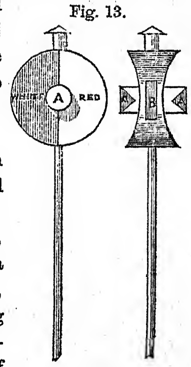
Turn-tables.—To enable single carriages to be shifted from one line of rails to another, and to enable engines and tenders to be turned round, *turn-tables* are used. They are practically formed of a pair of girders of sufficient length to receive the wheels of a carriage, braced together, and revolving round a pivot; and hence simplicity and strength are the main desiderata in their construction. They are generally from 11 feet to 13 feet in diameter, and those for turning an engine and tender without uncoupling, 30 feet in diameter. The small ones have usually been made of cast iron, but lately boiler-plate, strengthened with angle-iron, has been proposed by Mr. P. W. Barlow. Great solidity in the foundation, to insure an equal bearing, is required, and the tables may revolve on rollers or on shot. A pair of iron girders or wooden beams, braced together and supported at the centre and ends on rollers, to which rack and pinion work is attached, form a good substitute for a turn-table. Rolling platforms are occasionally used to transfer carriages from one line of rails to another. (See Plates VIII. IX. X. XXVI. XXVII.)

Sidings.—Sidings, or branch railways, for the reception of trains or carriages which are required to be off the main line, are provided at or near stations, as well as, at intervals, on railways with only a single line of rails: except near the points of junction, they should be at least 6 feet distant from the main line, as should also be all parallel lines of rails.

Signals.—The question of signals on railways is one of paramount importance; for the freedom of trains from accidents when moving at high velocities depends greatly upon the facility with which signals are seen, and the efficiency with which they are worked. At all places on a railway where engines or trains are usually stopped, permanent signal-posts should be erected, by means of which easily intelligible signals may be made in each direction, and also at level crossings near curves or steep gradients, where, the view being obstructed, especial precautions are required. For these purposes

the *semaphore* signal has been found to answer remarkably well. In it an arm, painted red, extended thus,  signifies 'caution,' and thus,  signifies 'danger,' or 'stop,'—the arm being suffered to hang down vertically to signify that the line is clear and all is right for an approaching train to proceed. These arms are usually made to work simultaneously with and by means of the same handle as lamps,—a green light being shown to represent 'caution,'—a red light, 'danger,'—and a white light to signify 'all right.' As an auxiliary to these signals, additional posts with arms are now very generally placed at 600 and even at 800 yards from the principal stopping-places, so as to give timely notice to engine-drivers of any obstruction in case of fogs or hazy weather. These signals are easily worked from a lever by wires laid by the side of the railway, supported on friction rollers fixed to short posts. When required to be carried round curves, lateral rollers are also used, the limit to the distance at which these signals can be placed being the extent of view of the man who works them at the lever. It is very desirable that in all cases, where practicable, the signals at a station should be all under the control of one man, who should also, if possible, have a handle in his box to work the points, with an indicator to show when they are properly closed. The signal box should, if possible, be elevated.

Fig. 13.



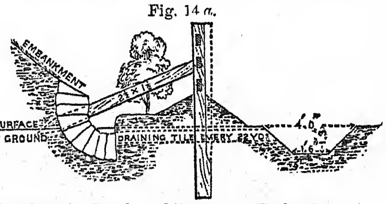
A A. Reflectors.
B. Glass door for inserting light.

The annexed sketch shows a good form of danger signal when the points are not set to the main line. The rod is connected with, and turns with, the movement of the switch handle.

In addition to the above-mentioned signals, hand signals, such as flags or lamps, green, red, and white, are used: and a code of signals is also adopted for plate-layers and labourers, &c., such as waving a hat in a particular manner, or placing the body in a particular position. And in foggy weather, detonating signals, to be fixed to the rail and fired by the wheel of the engine, are of great service, as well as torches stuck in the ground and set to burn for ten minutes or a quarter of an hour.

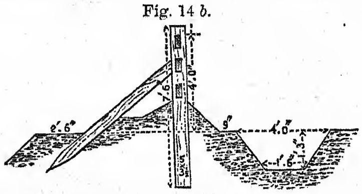
Fencing.—The fencing should be sufficient to prevent all animals from straying upon the railway, and may consist of a sunk wet fence, a stone wall, a close well-grown quickset hedge, a post and rail, or any other material which may suggest itself as being efficient and at the same time most economical, and will vary with the locality and the means afforded by it.

Fig. 14 *a*.



Section of a Ditch and Rail at an Embankment.

Fig. 14 *b*.



Section of a Ditch and Rail at an Excavation.

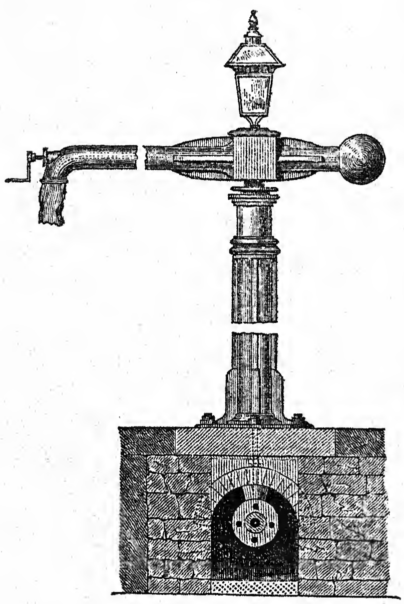
The cost, at the present time in England, of permanent fencing of posts and four rails, creosoted, including ditches, but without quicking, one side only, may be assumed to vary from 2*s*. 4*d*. to 3*s*. 3*d*. per foot run; average 2*s*. 10*d*.

Stations. (Plates XI. XII. and XIII.)—The number, position, and size of the stations will depend upon the nature, extent, and occupations of the surrounding

population; and their judicious adaptation to local circumstances will exercise an important influence on the development of traffic on the line. In towns they should be conveniently accessible from leading thoroughfares; and in selecting their positions in the country, great judgment is required to plan them so as to accommodate the largest amount of population. The average number of stations on the lines at present open for traffic in Great Britain is one in every three miles.

The accommodations of the stations should be such as to suit the requirements of the traffic, and should afford a ready means of taking up and depositing passengers, luggage, goods, cattle, carriages, &c., &c., if necessary; as, on account of the expense, it may not be desirable to provide for all these conveniences at every station; and it may be observed, that in general the requirements cannot be ascertained before the opening of a railway, and the consequent development of the traffic. As on this last account stations frequently require increased accommodation from time to time, it is advisable in the first instance to obtain ample space, and to construct the station on a plan capable of being enlarged. In addition, however, to these considerations respecting the traffic, others, connected with the working of the line, must operate with the Engineer in the choice of position and the construction of the stations. Supplies of water for the engines should be provided at about every twenty miles, depending on the means of obtaining it, on the gradients, and on the class of engine employed. The water is usually conveyed into the tender by means of a water-crane, of which a drawing is given in Plate XXV. and Figs. 14 *c* and 14 *d*, and, to economise fuel, is frequently heated previously. A renewal of the supply of fuel is similarly required. When it can be done, it is desirable to place a station on a level so situated as to have descending gradients on each side, which facilitates the stopping and starting of the trains. Details of construction are not given here, as they are equally applicable to other buildings; but it may be observed that the principal requirements, in addition to the offices, are large spaces under cover for the platforms, the carriages, &c., as also stables for spare engines (see Plate XII.),—and, at particular places, workshops for the repair of the stock, &c. Hence has arisen the introduction of roofs of large span, in which lightness and cheapness of construction are the main points to be attended to. These considerations, together with the large space required for a station, point out as the most eligible site (*cæteris paribus*) one with an even surface on the level of a railway, as that would involve the least amount of labour to adapt it to its object.

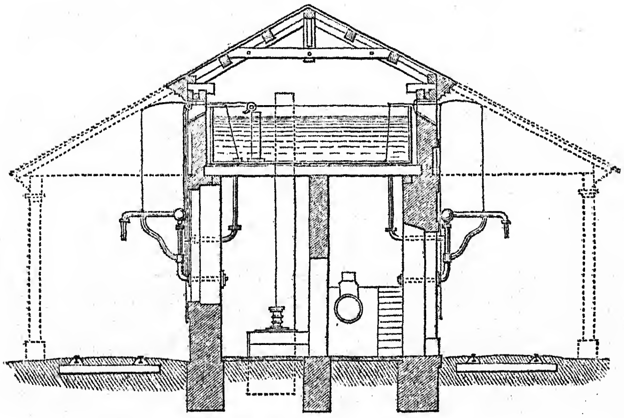
Fig. 14 *c*.



Bracket Water-Crane.

It would be beyond the intention of this article to describe the mode of fitting up and the articles required for the workshops for the repair of engines, carriages, &c.,

Fig. 14 *d*.



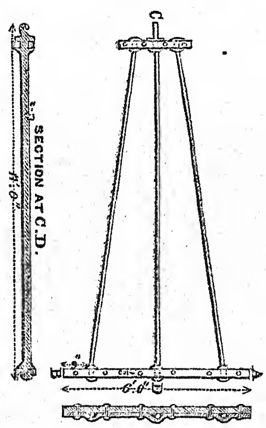
Water-Crane, supplied from Cistern above.

as they are similar to those required for other purposes. It may, however, be desirable to notice the mode of making coke, as the expense of locomotive power is materially dependent upon the cost of the fuel. The process of coking appears to free the coal from the impure gases and volatile parts, and from a proportion of the sulphur contained in it; and although the heating power of coke is less than that of coal, coke is used in locomotive engines on account of its freedom from smoke, and, consequently, not blocking up the tubes of the boiler. Coal also cakes, and requires to be frequently stirred, whilst coke will remain for a long time in an ignited mass, through which the air can pass; and hence a different construction of grate is required for each.

The best description of coals for coking is stated to be the poorer sort, and not the rich coals adapted to household use. Freedom from sulphur is also desirable.

Coking ovens should be placed (when it is determined by a Railway Company to erect them) on that part of the railway where coal is cheapest. Plates XIV. and XV. exhibit a plan and sections of a coking oven, on what is believed to be the best and most approved construction.

Fig. 15.



SECTION AT A B.

To make Coke.—After the completion of the ovens, they are gradually heated by a slow fire, to dry the brickwork and cause evaporation: by degrees, the fire is increased for about seven or eight days, at which time the oven is ready to receive the first charge of coals. The coal is placed in the oven on an iron cradle, shewn in plan and section in the accompanying sketch. This cradle is used to assist the discharge of the ovens, and is of a shape to diminish the liability of the coke catching in the sides of the oven. When charged, the mouth of the oven is bricked up with fire-bricks without mortar, and the doors (which are of iron) closed, and the sides and top and bottom and centre division plastered over with fire-clay to exclude the air: the coal gradually ignites, the draught being regulated according to

circumstances, as the state of wind, &c., by brick dampers, shewn at the top (see Plate XV.), which require to be constantly looked after. To assist the kindling, and prevent it from being the outer layer of coals alone which become ignited, the *bottom draught*, shewn in Plate XIV., is left open until the fire reaches the proper height, after which it is closed at the option of the burner. This draught is also required to allow the foul air to escape. The *top draught*, to carry off the evaporation, is left open for about five-sixths of the time of burning. When the whole mass is red-hot, and an almost smokeless flame issues from it, which, after continuing for some time, gradually decreases, it is time to discharge the oven. The coke is then drawn out, and water thrown over it to quench it. As soon as the coke has been removed, the ovens are refilled with coal, which the heat of the ovens is sufficient to ignite: 48 hours are sufficient to convert some sorts of coal into coke, whilst others require 96 or 120 hours. The loss of weight in converting coal into coke is about 40 per cent., *i. e.*, a given weight of coals will become about two-thirds as coke.

The following are the particulars relating to some ovens built at Bridgewater, by the Bristol and Exeter Railway Company, on the principle shewn in the drawings: the labour of coking amounts to 11*d.* per ton; and

1 ton of Cardiff coal	produces	13	cwt.	of coke.
,,	,,	6	,,	waste.
,,	,,	½	,,	small coke of no value.
,,	,,	½	,,	ashes fit for lime-burning.
		20 cwt.		

Electric Telegraph.—The electric telegraph,* from the facilities it affords for transmitting messages, &c., has become so integral a part of the efficient working of railways, that it appears desirable to mention here some particulars connected with it. Various methods have been proposed for making and registering the signals: that most commonly in use in Great Britain is the Needle Telegraph, on which the signals are read off and written down at the rate of from about seventeen to twenty-five words per minute. In America, various modes of self-registering telegraphs have been proposed. The wires are carried alongside of the railways by earthenware supports attached to posts. The number of the wires is proportioned to the expected number of messages, and while some are reserved for the through communication, others are applied to the intermediate stations, which may be put in connection with each other, or with branch lines, by means of turn-plates. The wires are covered with gutta-percha, to isolate them in passing through tunnels or near buildings, but in other places they have no covering; and in consequence, in very damp weather, it sometimes happens that the circuit, instead of being completed at the station the message is intended for, is completed along one of the other wires; and any increase to the force of the battery only tends to render this more certain in such cases. Messages can almost always be transmitted to a distance of 100 miles, but a clear state of the atmosphere is required to transport a message 300 miles. The needles are subject to disturbances from magnetic storms, for which a correction is introduced into the machines, and during thunder-storms they are liable to be demagnetized, should the lightning strike the wires: to obviate this, however, conductors have been introduced.

Working Stock.—The term 'rolling stock,' or working stock on a railway, implies

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* See article 'Telegraph, Electric.'

the *matériel* for conveying the traffic, and includes engines, carriages, horse-boxes, trucks, goods-waggons, cattle-waggons, ballast-waggons, &c. Its cost depends so entirely upon the nature and amount of the traffic, that no estimate of it can be given. In Great Britain, however, the cost on the principal lines now in operation has averaged from £2000 to £3000 per mile.

Under the head of 'rolling stock' should be included the stationary plant, or machinery and tools in the workshops, which afford means of repair.

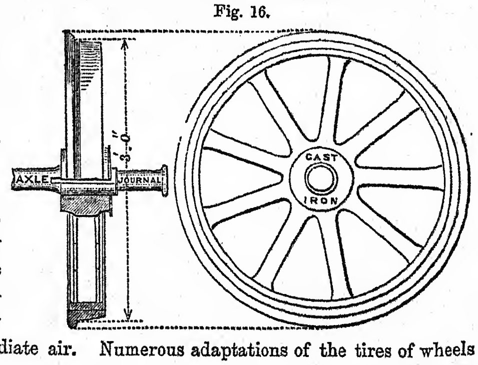
Carriages, Waggons, &c. (Plates XVI. to XXIV.)—The forms and dimensions of the various parts of the carriages and waggons at present in use on railways is the result of their gradual adaptation to the required strength and fitness, and not of any previously laid down general rule; and the various improvements they have undergone appear to have rendered them well adapted to their purpose.

The description of rolling stock to be selected for a railway will depend upon the nature of the anticipated traffic; and in the following remarks it is intended to convey an idea of the main points to be attended to.

The general construction of carriages and waggons, and their proportions in the several trains, should be such as to bring the average load conveyed as near as possible to the maximum load. In the conveyance of goods this is comparatively easy, but the varying numbers and divided classes for passengers entail a great loss of space.

Wheels.—The wheels of railway carriages should be uniform: the proper size appears to depend upon the following conditions, viz.: the power required for the draught of wheel carriages depends principally on the friction of the axles and the surface resistance of the road, both of which may be assumed as proportionate to the insistent weight: the wheels do not add to the weight on the axles, but they do to the weight on the road; hence, although an increase of diameter will not diminish the friction on the axles, it *may* increase the surface resistance; and hence there is a limit to the advantage to be derived from increasing the size of the wheels.

Fig. 16.



The accompanying figure shews the general form of a railway carriage wheel as at present in use, although the particular modes of construction, as to spokes, &c., vary so much as to render any description of them beyond the limits of this article. Solid wheels have been proposed, with a view of diminishing the atmospheric resistance; but at high velocities the spokes would carry round with them the intermediate air. Numerous adaptations of the tires of wheels have been attempted to obviate the danger of accident from their breaking or flying off, but none have yet been found to prevent, at all perfectly, the risk of damage. It has not hitherto been found practicable to adapt the wheels to work independently of each other on the axles, which, if accomplished, would do away with a principal cause of resistance in going round curves. This resistance is, however, to a certain extent, diminished by the coning of the wheels.

Axles of Carriages.—The axles of railway carriages appear to be exposed to the following strains, viz.:

1st. That arising from the weight of the waggon and load, which acts on the

journal, and is increased by the momentum acquired by the load in falling through spaces caused by inequalities in the road.

2ndly. That arising from the oscillation of waggons on curves, due to imperfect coupling and to lateral play between the flanges of the wheels and the rails.

3rdly. That due to starting and stopping trains.

4thly. The torsion caused by the dragging of the wheels in going round curves, and by inequalities in the size of the wheels, or in their balancing, or in the journals, brasses, &c.

The axle is also subject to constant vibration.

From these causes it is most desirable that great care should be exercised in selecting the best fibrous iron for axles.

Springs.—The strain on the axles due to the inequalities in the road is diminished by the use of springs, which should be so proportioned as to sustain the load easily, yielding equally in all carriages with the maximum load, and sufficiently elastic to absorb the effect of the oscillation of the load; to assist which, therefore, the load should be distributed equally on each side of the carriages.

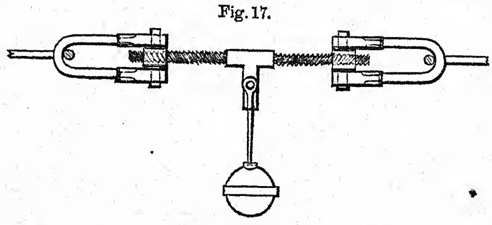
Axle-boxes.—The springs are connected with the journal by means of the axle-boxes. In some very long carriages which have been lately introduced on some lines of railway, the axle-box is allowed considerable lateral play on the journals, to enable these long carriages the more easily to pass round curves.

Framing.—The strength of carriages depends mainly on the mode in which they are framed, and the framing should be of similar construction for carriages intended to run in the same trains. The newest arrangements for timber framings are shewn in the accompanying Plates.

Coupling and Buffers.—To obviate the oscillations of carriages and waggons which produce strains on the axles and other parts, injury to the roadway, and deterioration to the loading, the connection between the carriages of a train should resemble as much as possible the jointing of the vertebræ in an animal's back-bone, by which means the lateral action of a carriage would be neutralized by the support of the neighbouring ones.

The buffers should be of the same size and height, and be constructed with springs; the carriages in a train should be coupled and drawn in the same manner by means of screw couplings and spring draw-bars; the draught acting always from the centre. The methods at present adopted for coupling and drawing the trains are, however, open to great improvement. The mode of coupling waggons in goods trains without spring buffers or draw-bars, and by a chain only, is liable to lead to accidents from the play which must necessarily be allowed between the waggons to admit of their going round curves; since each time the speed is slackened the waggons close up, and, at a fresh start, the chains are exposed to a sudden jerk. The forms (Figs. 17*a*, 17*b*) have been adopted on the German Railways. These jerks occasionally break the chains, which render a double connection desirable, and they are also liable to become unhooked in stopping, but this would be obviated by a simple arrangement. It is not safe to place this description of waggon in passenger-trains, especially when running at high velocities.

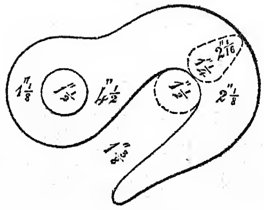
Fig. 17.



Screw Coupling.

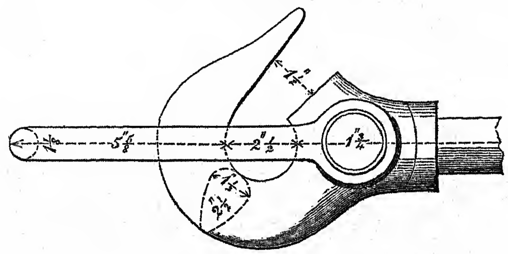
Passenger-Carriages.—The arrangements for the parts of the carriages or waggons above the framing depend upon the description of the traffic for which they are intended. Those for passengers afford conveniences according to the class to be conveyed, and the classification will depend on the nature and habits of the population of the country. In Great Britain there are three classes, and the compartments of the carriages are

Fig. 17 *a.*



Hook for Coupling-Chain.

Fig. 17 *b.*



Hook for Draw-Bar.

small; whilst in America there is only one class, and a passage down the centre of the train renders the whole of the seats accessible from one end to the other. Wrought iron has latterly been used by several Railway Companies as a material for the construction of the upper portion of both carriages and waggons.

Cattle-Waggons.—The dimensions of cattle-waggons depend upon the description of stock and average load to be conveyed, whilst facilities should be afforded to persons who would load an entire waggon. The springs for the buffers and drawbars in these and other goods-waggons are frequently made of vulcanized India-rubber.

Goods-Waggons. (Plates XXI. and XXII.)—For goods requiring care, high-sided covered waggons have been found so much more advantageous than open waggons, from affording security from the weather and from packages falling off, as well as effecting a saving in tarpaulins, as to compensate for their increased expense. For mineral traffic, the low-sided goods-waggons are generally in use, the weight of the waggon and load being usually limited to from six to eight tons.

The following Table will give an idea of the weight and cost of rolling stock, and may be assumed as a fair general average of prices, &c.

Description.	Weight.	Rate.
	Tons.	£
Locomotive engines and tenders, empty . .	18 / 7	2200
1st-class carriages	$3\frac{1}{4}$	300
2nd ,, ,, ...	3	220
3rd ,, ,, ...	$3\frac{1}{4}$	200
Composite carriages, or 1st and 2nd class combined .	4	600
4th-class carriages, without seats, separated by railing	$3\frac{1}{2}$	200
Post-office carriages and tenders	6	200
Trucks	3	120
Horse-boxes	$3\frac{1}{2}$	120
Goods-waggons	$2\frac{1}{2}$	100
Cattle and sheep cages	3	100
Iron hopper coal waggons	2	70

Brakes.—To enable trains to be stopped in a moderate distance, brakes are applied

to the wheels of some of the carriages, or guard-vans are attached to the trains. The number of brake-carriages or vans per train will depend on the inclinations on the line and the speeds employed: with passenger-trains it has been considered that on an average, and to insure safety, every fifth carriage should have a brake: the engine also is generally reversed to assist the brakes. It must be recollected, however, that by stopping a train too rapidly, great injury results both to the permanent way and the rolling stock. (See Plate XXIII.) But still it is very important that those who have charge of a train should be able to stop it within a very short distance, when there is risk of collision, or any other danger is apprehended; and the greater the number of wheels to which brakes are applied, the more speedily will the effect be produced.

The following considerations appear to be those which would determine the amount of brake-power.

The forces which act on the train after the steam has been shut off are the axle friction and rolling friction of the train, and the pressure of the wind: the friction tends gradually to bring the train to rest,—the pressure of the wind to accelerate or retard it, as the case may be, and this will therefore be omitted from the conclusions to be drawn.

To stop a train rapidly, brakes are applied to some of the wheels, and the engine is reversed. The application of brakes prevents the wheels from revolving, and introduces the friction due to the weights on the wheels to which the brakes are applied. The act of reversing the engine does not immediately stop the forward motion of the driving-wheel, but forces it to revolve at a somewhat slower rate than that due to the speed of the train, and thus causes a friction of surfaces to take place between the wheel and rail.

The axle and rolling friction of the train may be assumed to be some proportion of the total weight of the train; the friction of the wheels to which brakes are applied may be taken as some proportion of the insistent weights; from experiments,* it appears that the axle and rolling friction may be taken at $\frac{1}{334}$th part of the weight of the train, and the friction due to the brakes at about $\frac{1}{8}$th of the weights on them.

Hence, if l represent the gross load of the train,
w ,, the weights on the wheels to which brakes are applied,
R ,, the retardation in feet per second,
g ,, the force of gravity,

and, if the train be on an incline,

$\frac{1}{p}$ represent the slope of such incline,

$$R = \left(\frac{l-w}{334} + \frac{w}{8} \pm \frac{l}{p}\right)\frac{g}{l},$$

the latter term being used with the negative sign when the train is descending and the positive sign when ascending the gradient.

If S = space traversed by train in coming to rest,
v = velocity in feet per second at the moment the steam is shut off and the brakes applied,

$$S = \frac{v^2}{2R}.$$

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* Made in October, 1849, by Capt. Laffan, R.E.

In estimating practically the space which would be required for a train to stop in, one or two seconds should be allowed for time lost in applying the brakes.

Locomotive Engines.—Before proceeding to consider the cost of maintaining and of working a railway, it appears desirable to state the conditions upon which the powers of locomotive engines depend, and the principles which determine the form and class of engine to be selected for a particular line.

The dimensions of the several component parts of an engine will be regulated by the nature of the line it is to be employed upon, the description of the traffic, and the speed required.

The steam-power of an engine applied to the pistons is transferred to the load through the friction of the driving wheel on the rail; as long, therefore, as the amount of steam at the required pressure which can be produced by the evaporation of water in the boiler is sufficient to counterbalance what is taken away for the cylinders, the adhesion of the driving wheel on the rail will limit the load which can be drawn. But as the speed increases and the alternations of the pistons become so rapid as to take out the steam faster than it can be produced at the requisite pressure in the boiler, the pressure of the steam in the cylinders will diminish with the increased volume, and the pressure on the pistons will then limit the load.

With passenger traffic, or traffic at high speeds and with light loads, a large driving-wheel is advantageous; whilst with goods traffic, or traffic at low velocities, where heavy loads are drawn, it is usual to make all the wheels of equal size, and to couple them together, in order to obtain a larger amount of adhesion. The driving-wheels of the largest passenger-engines in this country are made from 6 to 8 feet in diameter. Care must be taken so to arrange the parts of the engine with a large driving-wheel, that the centre of gravity shall be kept as low as possible. The wheels of goods engines are usually 5 feet diameter.

The area of the cylinders determines the amount of power which can be applied to the driving-wheel, but it is limited by the evaporative power of the boiler: the diameters of the cylinders of the largest engines now in use vary from 15 to 18 inches. The position of the cylinder has a great influence on the steadiness of motion in the engine, and this is conducive to safety, and diminishes the wear and tear upon the machinery and road. A horizontal cylinder, with a long-connecting rod, is the arrangement least liable to cause oscillation. The actual power applied to the pistons is diminished by the back pressure on the pistons, from the steam not having time to escape from the cylinder after the stroke and before the return of the piston: this will depend partly on the velocity of the piston, partly on the elasticity of the steam at the end of the stroke, and partly on the relative areas of the escape-pipe and cylinders. The whole power of the steam is only required to act upon the pistons when an engine begins to move from a state of rest, because when the velocity acquired becomes uniform, the power of the steam need only operate to overcome the friction which would otherwise soon cause the train to stop: hence, in order to diminish the back pressure, and also to economise fuel, it is usual to work engines expansively; that is, to cut off the steam when the piston has passed through a portion of the stroke, and allow the expansion of the steam to carry it through the remainder. The proportion of the length of the stroke at which it is considered advisable to cut off the steam depends upon the power of the boiler to generate steam, since the introduction of steam in an expanded state into the smoke-box renders the blast feeble, and diminishes the amount of steam generated by the boiler. The proportions will therefore vary with the relative size of the grate, boiler, and cylinder, as well as with the speed and power required to be exerted. With engines on the narrow-gauge lines it is usual to cut off the steam at from $\frac{5}{8}$ to $\frac{7}{8}$ of the stroke. In the 'Great

Table of the Elastic Force of Steam, and corresponding Temperature of the Water with which it is in Contact.

Pressure on a square inch, including the pressure of the atmosphere.		Elastic force in		Temperature in degrees of			Volume of steam compared with the volume of water.	Pressure on a square inch, including the pressure of the atmosphere.		Elastic force in		Temperature in degrees of			Volume of steam compared with the volume of water.
		Inches of mercury.	Metres of mercury.	Fahrenheit.	Reaum.	Cent.				Inches of mercury.	Metres of mercury.	Fahrenheit.	Reaum.	Cent.	
lbs.	kilog.							lbs.	kilog.						
14·7	6·668	30·00	·762	212·0	80·0	100·0	1700	63	28·57	128·52	3·266	299·2	118·8	148·4	449
15	6·80	30·60	·778	212·8	80·4	100·4	1669	64	29·03	130·56	3·318	300·3	119·2	149·1	443
16	7·26	32·64	·829	216·3	81·9	102·4	1573	65	29·48	132·60	3·370	301·3	119·7	149·6	437
17	7·71	34·68	·880	219·6	83·3	104·2	1488	66	29·93	134·64	3·422	302·4	120·2	150·2	431
18	8·16	36·72	·932	222·7	84·7	105·9	1411	67	30·39	136·68	3·474	303·4	120·6	150·8	425
19	8·62	38·76	·984	225·6	86·0	107·6	1343	68	30·84	138·72	3·526	304·4	121·1	151·3	419
20	9·07	40·80	1·037	228·5	87·3	109·2	1281	69	31·29	140·76	3·577	305·4	121·5	151·9	414
21	9·52	42·84	1·089	231·2	88·5	110·7	1225	70	31·75	142·80	3·629	306·4	122·0	152·4	408
22	9·98	44·88	1·140	233·8	89·7	112·1	1174	71	32·20	144·84	3·681	307·4	122·4	153·0	403
23	10·43	46·92	1·192	236·3	90·8	113·5	1127	72	32·66	146·88	3·733	308·4	122·8	153·6	398
24	10·88	48·96	1·244	238·7	91·9	114·8	1084	73	33·11	148·92	3·785	309·3	123·2	154·1	393
25	11·34	51·00	1·296	241·0	93·0	116·1	1044	74	35·36	150·96	3·837	310·3	123·7	154·6	388
26	11·79	53·04	1·348	243·3	93·9	117·4	1007	75	34·02	153·02	3·889	311·2	124·1	155·1	383
27	12·25	55·08	1·400	245·5	94·9	118·6	973	76	34·47	155·06	3·940	312·2	124·5	155·7	379
28	12·70	57·12	1·452	247·6	95·8	119·8	941	77	34·93	157·10	3·992	313·1	124·9	156·2	374
29	13·15	59·16	1·503	249·6	96·7	120·9	911	78	35·38	159·14	4·044	314·0	125·3	156·7	370
30	13·61	61·21	1·555	251·6	97·6	122·0	883	79	35·83	161·18	4·096	314·9	125·7	157·2	366
31	14·06	63·24	1·607	253·6	98·5	123·1	857	80	36·29	163·22	4·148	315·8	126·1	157·7	362
32	14·51	65·28	1·659	255·5	99·3	124·2	833	81	36·74	165·26	4·199	316·7	126·5	158·2	358
33	14·97	67·32	1·711	257·3	100·1	125·2	810	82	37·19	167·30	4·252	317·6	126·9	158·7	354
34	15·42	69·36	1·763	259·1	100·9	126·2	788	83	37·65	169·34	4·303	318·4	127·3	159·1	350
35	15·87	71·40	1·814	260·9	101·7	127·2	767	84	38·10	171·38	4·355	319·3	127·7	159·6	346
36	16·33	73·44	1·866	262·6	102·5	128·1	748	85	38·55	173·42	4·407	320·1	128·0	160·1	342

37	16·78	75·48	1·918	264·3	103·2	129·1	729	86	39·01	175·46	4·459	321·0	128·4	160·6	339
38	17·23	77·52	1·970	265·9	104·0	129·9	712	87	39·46	177·50	4·511	321·8	128·8	161·0	335
39	17·69	79·56	2·022	267·5	104·7	130·8	695	88	39·91	179·54	4·563	322·6	129·2	161·4	332
40	18·14	81·60	2·074	269·1	105·4	131·7	679	89	40·37	181·58	4·615	323·5	129·6	161·9	328
41	18·59	83·64	2·126	270·6	106·0	132·6	664	90	40·82	183·62	4·666	324·3	129·9	162·4	325
42	19·05	85·68	2·178	272·1	106·7	133·4	649	91	41·27	185·66	4·718	325·1	130·3	162·8	322
43	19·50	87·72	2·229	273·6	107·4	134·2	635	92	41·73	187·70	4·770	325·9	130·6	163·3	319
44	19·96	89·76	2·281	275·0	108·0	135·0	622	93	42·18	189·74	4·822	326·7	131·0	163·7	316
45	20·41	91·80	2·333	276·4	108·6	135·8	610	94	42·64	191·78	4·874	327·5	131·3	164·2	313
46	20·86	93·84	2·385	277·8	109·2	136·6	598	95	43·09	193·82	4·926	328·2	131·6	164·8	310
47	21·32	95·88	2·437	279·2	109·9	137·3	586	96	43·54	195·86	4·977	329·0	132·0	165 0	307
48	21·77	97·92	2·489	280·5	110·4	138·1	575	97	44·00	197·90	5·029	329·8	132·4	165·4	304
49	22·22	99·96	2·541	281·9	111·1	138·8	564	98	44·45	199·92	5·081	330·5	132·7	165·8	301
50	22·68	102·00	2·592	283·2	111·6	139·6	554	99	44·90	201·96	5·133	331·3	133·0	166·3	298
51	23·13	104·04	2·644	284·4	112·2	140·2	544	100	45·36	204·01	5 185	332·0	133·3	166·7	295
52	23·59	106·08	2·696	285·7	112·8	140·9	534	110	49·89	224·40	5·703	339·2	136 5	170·7	271
53	24·04	108·12	2·748	286·9	113·3	141·6	525	120	54·43	244·82	6·222	345·8	139·5	174·3	251
54	24·49	110·16	2·800	288·1	113·8	142·3	516	130	58·97	265·23	6·740	352·1	142·3	177·8	233
55	24·95	112·20	2·852	289·3	114·4	142·9	508	140	63·50	285·61	7·259	357·9	144·8	181·1	218
56	25·40	114·24	2·903	290·5	114·9	143·6	500	150	68·04	306·03	7·778	363·4	147·3	184·1	205
57	25·85	116·28	2·955	291·7	115·4	144·3	492	160	72 57	326·42	8·296	368·7	149·6	187·1	193
58	26·31	118·32	3·007	292·9	116·0	144·9	484	170	77·11	346·80	8·814	373·6	151·8	189·8	183
59	26·76	120·36	3·059	294·2	116·5	145·7	477	180	81·65	367·25	9·333	378·4	153·9	192·4	174
60	27·21	122·40	3·111	295·6	117·2	146·4	470	190	86·18	387·61	9·851	382·9	156·0	194·9	166
61	27·67	124·44	3·163	296·9	117·7	147·2	463	200	90·72	408·04	10·370	387·3	157·9	197·4	158
62	28·12	126·48	3·215	298·1	118·3	147·8	456								

Britain,' a broad-gauge engine, with an 18-inch cylinder and a 24-inch stroke, the steam is cut off at 18 inches when starting a heavy train,—at $16\frac{7}{8}$ inches when the full power of the engine is required, at from 40 to 50 miles per hour,—at $14\frac{3}{8}$ inches when the full power is required at higher speeds. The degree of nicety with which the motion of the side-valve is timed relatively to the motion of the piston, operates strongly upon the consumption of the fuel.

The steam, after leaving the cylinder, is conveyed through the escape-pipe into the chimney, where, by forcing out the air, and then condensing it, it increases the draught of the fire,—the larger the amount of air displaced by the steam, the greater the blast created; whence it would appear that the lower the mouth of the escape-pipe is placed, the better,—remembering that it must be kept above the tubes of the boiler.

The evaporating power of the boiler will depend upon its size and form, as well as upon the size and form of the fire-box: the surface exposed to heat is increased by the use of tubes, the number of which will of course vary with their diameter; and this is determined by considering that while the smaller diameter increases the amount of surface exposed to heat, it tends to diminish the draught of the fire, and renders the tube liable to be choked with dust. The diameter which has been generally adopted is about $1\frac{1}{2}$ inch internally. The tubes are of brass, and are found to wear out much more rapidly at the end adjacent to the firebox than at the other end,—chiefly, it is supposed, on account of the small particles of coke carried through them by the draught.* It would be beyond the limits of this article to enter upon the details of the component parts of locomotive engines, more particularly as the subject is be treated under a separate head.† It is considered that 1 ℔. of coke usually evaporates 8 ℔s. of water,—or $1\frac{1}{4}$ ℔. of coke per gallon of water. The Table, pages 237, 238, shews the relation between the bulk, pressure, and temperature of steam.

The largest engine on the narrow gauge will evaporate from 200 to 230 cubic feet of water per hour, and the largest which have been constructed for the broad gauge from 300 to 350 cubic feet. The following dimensions are stated to be those of the largest engines now in use.

GOODS-ENGINES.

	Narrow Gauge.	Broad Gauge.
Diameter of cylinder	16 to 18 inches	16 inches.
Length of stroke	22 to 24 ,,	24 ,,
Diameter of driving-wheel	4 ft. 6 in. to 5 ft.	5 ft.

Wheels all coupled, with a weight of from 8 to 10 tons on each pair; total weight of engine about 24 to 30 tons.

PASSENGER-ENGINES.

	Narrow Gauge.	Broad Gauge.
Diameter of cylinder	15 to 16 inches	18 inches.
Length of stroke	21 inches	24 ,,
Diameter of driving-wheel	6 ft. to 8 ft.	8 ft.
Weight on driving-wheels	8 to 14 tons	$10\frac{9}{10}$ tons.
Weight of engine	18 to 25 ,,	31 ,,

The weight on the driving-wheel should be regulated by the power in the cylinder to

* The amount of pressure which any boiler is *constructed* to bear should be marked upon it; it should also be subjected to a periodical examination, to ascertain whether it is beginning to wear, and the probable safe pressure on the *weakest* part registered; and one safety valve should be placed out of the control of the engine-driver.—*Editor.*

† See article "Steam-Engine."—*Editors.*

overcome the adhesion, and by the strength of the permanent way. The adhesion may be taken as high as $\frac{1}{6}$th the weight on the driving-wheels; but when the rails are slippery, it is sometimes as low as $\frac{1}{20}$th.

Resistances to Trains.—The resistance to which railway trains are exposed is an important subject of inquiry, but a sufficient number of experimental facts has not yet been collected to establish a perfect formula.

The resistance in calm weather may be considered to be made up of three parts: 1st, the friction of the wheels and axles of the train, which is independent of the velocity, but varies with the weight; 2nd, the resistance due to concussions and oscillations of the train, which will, it may be assumed, vary with the velocity and with the weight; 3rd, the resistance from the air, which will vary with the square of the velocity and the frontage area of the train.

Mr. Wyndham Harding, in a paper read to the Institution of Civil Engineers in 1846, deduced from experiments a formula combining all these points.

Taking the friction of the train at 6 lbs. per ton, and putting

T = tons weight of the train,

V = velocity in miles per hour,

N = area of frontage,

$\cdot 0025$ lbs. = resistance from air per square foot of frontage, at 1 mile per hour,

and assuming the resistance from concussions at $\frac{V}{3}$, he called the resistance of the train $= \left(6 + \frac{V}{3} + \frac{V^2 \times \cdot 0025 \times N}{T}\right)T$. On a careful comparison of this formula, which was derived from experiments on the narrow-gauge lines, with some experiments made by Mr. Gooch on the Great Western Railway, in 1848, it appears probable that Mr. Wyndham Harding has assumed too high a value for the second term of his equation, since the difference between the formulæ would be more than compensated for by a difference in the character of the roads, and the experiments show the great importance of easy motion in the engine and train, and a good road: besides, although the resistance from friction is independent of velocity, that due to abrasion, or the wearing away of surfaces, is not so; and this may to a certain extent enter into the first term: the effect of wind, also, on the side of the train will be considerable. On the whole, therefore, it appears impossible to assume a formula which can be at all satisfactory, before the several elements shall have been determined by more numerous experiments under varying conditions of weather and of permanent way.

In order, however, to form an idea of the steam power an engine is required to exert in drawing a train, after being diminished by the back pressure, it may be assumed firstly, that the friction of the engine gear is, when reduced to the circumference of the driving-wheel, about 6 lbs. per ton weight of engine and tender, and 1 lb. additional for each ton of load; secondly, the resistance of the train is made up partly of the journal friction of the axles,—partly of the resistance of the air to the rotation of the wheels and axles, which will vary with the velocity and dimensions of the wheels,—the rolling friction of the wheels on the rails,—and the atmospheric resistance of the train. This total train-resistance at low speeds is assumed to be 8 lbs. per ton weight of the train, but it increases rapidly with the increase of velocity; the following being the mean of the results given by Mr. Wyndham Harding and Mr. Gooch in their respective statements of the subject, viz.:—

At 10 miles per hour the resistance is			8 lbs. per ton.	
20	,,	,,	12	,,
30	,,	,,	16	,,
40	,,	,,	20	,,
45	,,	,,	22	,,
50	,,	,,	25	,,
55	,,	,,	27	,,
60	,,	,,	30	,,

Working Expenses.—The receipts from the traffic of a railway must be devoted, first, to pay for the maintenance and working of the line,—next, to the interest on the sum borrowed to assist in its construction, whilst the surplus remains as profit to the projectors of the line.

The annual charge upon a railway is partly independent of the amount of traffic, and partly dependent upon it.

The first or fixed charge is made up of the expenses of keeping the stations, tunnels, viaducts, slopes, drains, and fences in repair; a part of the expense of re-laying or renewing the sleepers, rails, ballasting, &c.; and a proportion of the expenses of management, such as the salaries of officers, police, and points-men, which, though they increase with the traffic, do not increase in proportion to it.

The other or varying charge is composed of the engine-men and fire-men's wages; the consumption of coke, grease, oil, &c.; the repairs of the engines and carriages; the wages of guards, porters, &c.; a proportion of the expenses of management and the maintenance of the permanent way, so far as it is affected by the traffic.

Maintenance of Way.—The expense of maintenance of way varies considerably from circumstances, and is rather a charge dependent on the character of the line and its original mode of construction, than on the amount of traffic; for although an increase of traffic increases the cost of maintenance, the difference between a maximum and minimum traffic is of less importance than that due to other causes. In a dry climate this would not probably be so much the case, but in this country a great part of the deterioration is due to the weather, and the expense will therefore vary with the depths and heights of the cuttings and embankments, and with the nature of the soil through which the railway passes. When a line is first opened for traffic, the expenses will be greater on account of the consolidation of the works, and any increased charge from this cause, or from the failure of works, may be fairly placed to the cost of construction.

Unfortunately, sufficient attention has not been paid, or rather, sufficient details have not been published, relative to the deterioration of the rails and sleepers, to enable any general information with respect to it to be given. It is considered, by one party, that after a certain period they must be entirely re-laid, and that the current repairs cannot perpetuate, but will only prolong, their existence; and therefore, that in addition to the annual outlay, a proportion of the cost of renewal should be set aside, so as to distribute the expense over the whole period of the duration of the rails;—whilst, on the other hand, and with an equal show of reason, it is urged, that from the great variety in the quality of both rails and sleepers, the annual number requiring repair, would, after a few years, become uniform, and that therefore, after the first few years, it is not necessary to form any reserve fund for renewals. Among the chief causes of wear and tear of rails and sleepers are the great weights and high speeds now in use, which, in passing over the inequalities at the joints, produce a series of blows: it is probable that some new mode of laying the roadway, better calculated than the present one to resist it, will ere long be adopted.

Captain Huish, in a pamphlet he published in 1849, considers that the rails and chairs will last 20 years, and the sleepers if creosoted, from 12 to 20 years; and he would lay aside from £50 to £60 per annum as a reserve fund for renewal. On the Belgian railways, where the speed and the traffic are much less than on English railways, it has been assumed that the rails and chairs would last 120 years, and that $\frac{1}{120}$th part of their value should be yearly laid aside,—the duration of the sleepers being not less than 12 years. It is probable that in some of the Colonies, with a favourable climate, moderate speeds, and a limited traffic, this assumption as to the average durability would not be far wrong.

Three men per mile may be assumed as a fair average of the number permanently employed as plate-layers, in adjusting the rails, &c.

Cost of Locomotive Power.—The expense on account of locomotive power depends upon the number of miles run by the engine, and is, to a great degree, independent of the weight of the train, except in extreme cases. The expenditure on different lines will vary with the facilities for obtaining coal and with the nature of the gradients.

The fuel consumed by an engine may be divided into that required for getting up the steam, the proportion consumed while standing in reserve, and that expended in drawing the load; and hence, in order to obtain the maximum return from an engine, not only is it necessary to proportion the load to its powers, but it is necessary also so to arrange the locomotive stock as to obtain from each engine in steam a maximum train mileage. As far as it can be estimated from the return of traffic on the best managed lines, it would appear that from 120 to 150 miles per day is the greatest average distance run by engines hitherto; and this probably for only four days out of the week.

An engine, it has been considered, will consume 15 lbs. of coke for itself and $\frac{1}{5}$ lb. additional per ton weight of train, some allowance being made for the consumption in getting up the steam: the cost of locomotive power, including interest on locomotive stock, may therefore be assumed at 7*d.* + cost of 40 lbs. of coke = 10*d.* to 13*d.* per mile; and an average of the locomotive charges, estimated from the half-yearly returns of nineteen Companies for the last half of the year 1847, gives the cost per mile at 12·12*d.* On the York, Newcastle, and Berwick Railway, however, the present average consumption of coke is 26 lbs. per passenger train per mile run, or 10 lbs. for the engine and 2 lbs. additional, per mile, for each carriage: the goods' trains vary in weight from 150 to 400 tons, and the average consumption of coke per train per mile, for goods' engines, is 50 lbs. To encourage the engine-drivers to save coke, it is the custom on many lines to give them a premium for all the coke saved under an average. On the above-mentioned railway, the engine-drivers receive 1*s.* for each lb. saved under the average per fortnight, and the fire-men 4*d.*

Wear and Tear of Carriages.—The charges for wear and tear of carriages, and interest on the capital invested in them, may be assumed at

1*d.*	per mile run for	first-class carriages,
$\frac{1}{2}$*d.*	,,	second-class ditto,
$\frac{1}{4}$*d.*	,,	third-class ditto, and waggons and trucks.

It has been estimated that on British railways the average daily mileage of 1st-class carriages, capable of containing 18 passengers, is 59 miles, and that they convey on an average 7 passengers;—of 2nd-class carriages, capable of containing 25 passengers, it is 45 miles, and they convey on an average 13 passengers; and of 3rd-class carriages the daily average mileage is 38 miles; they are capable of containing 32 passengers, and carry on an average 21,—whilst the average daily mileage of passenger carriages on French and Belgian lines is 39 miles. The average daily mileage of the

goods-carrying stock on British lines is 27 miles, and the average load $2\frac{1}{2}$ tons; whilst that on Continental railways is $16\frac{1}{4}$ miles. The comparatively small amount of daily mileage of goods-waggons is due to the time consumed in loading and unloading, and waiting for a complete train. It is stated that on the London and North-Western Railway the number of vehicles in a passenger train averages 7, of which 4 are passenger carriages, the gross load being 70 tons; and that the average weights of goods trains are 154 tons, or 120 tons net load, *i.e.* they contain about 24 waggons.

It is considered that the periodical repairs which the working stock of a railway undergoes keep it up to its effective value to the Company, and that hence no reserve fund is requisite for replacing it.

The total cost of working railway trains has been stated to be from 3*s.* to 5*s.* per mile, including everything; and the following classification of the items on the London and Birmingham Railway is given in the Appendix to a Report to the House of Lords on Railway Communication between London and Birmingham, published in 1848:

	s.	*d.*
Maintenance of way	0	$5\frac{1}{4}$
Locomotive power	1	0
Police	0	2
Coaching and Merchandise	0	$7\frac{3}{4}$
Coach and waggon repairs	0	$2\frac{1}{2}$
Depreciation of stock	0	4
Mileage duty	0	$5\frac{1}{2}$
Rates and taxes	0	3
General charges	0	2
Total	3	8

Goods trains cost 8*d.* per train per mile additional.

The following is an approximate analysis of the proportions between the several expenses of working and maintenance, obtained from five of the principal railways in this country, viz.:—

Direction and management	6·8
Maintenance of way and works	15·8
Locomotive power	35·1
Carrying department	38·6
Office and miscellaneous	3·7
	100·0

In some small lines, when ready money for the purchase of stock has not been easily procurable, agreements have been entered into, contracting for the working of the line, and it is under such circumstances alone that the system appears advisable. The North-Western Railway Company is one that has adopted this plan, and the North Staffordshire Railway Company another. In the first case, the contractor is bound to run trains capable of conveying 132 passengers each, at such times as the Company desire, at 1*s.* per train per mile, the contractor finding the engines, carriages, &c., and 6 per cent. additional being allowed him for shunting. The goods traffic the contractor conveys at 1*s.* 8*d.* per ton per mile, the waggons being found by the Company. The following Table shows the rates to be paid by the North Staffordshire Railway Company to the contractor, who finds all the locomotive stock, plant, &c.

Locomotive power per mile.				Carriages, &c., per mile.							
Miles per hour.											
30	40	18	12								
Passengers.		Goods or minerals weighing 120 tons.		1st Class.	Composite.	2nd Class.	3rd Class.	Horse-boxes.	Brake vans.	Carriage trucks, vans, &c.	Empty vans.
d. 13		*d.* $14\frac{1}{2}$	*d.* $13\frac{1}{2}$	*d.* $\frac{7}{8}$	*d.* $\frac{3}{4}$	*d.* $\frac{5}{8}$	*d.* $\frac{1}{2}$	*d.* $\frac{5}{6}$	*d.* $\frac{3}{8}$	*d.* $\frac{1}{2}$	*d.* $\frac{1}{4}$

The contractor is subject to certain charges for use of stationary plant, &c.

Cost of Working.—The following statement of the cost of working and maintenance for the half-year ending June, 1850, on the London, Brighton, and South Coast Railway, may prove interesting :—

Maintenance of way per mile run	6·16*d.*
Maintenance of way per mile of railway	£93.
Locomotive power per train per mile	$10\frac{1}{2}$.
Coach and waggon repairs per train per mile	$4\frac{1}{2}$*d.*
Coaching per cent. on coaching receipts	8
Goods charges per cent. on goods receipts	$13\frac{1}{2}$
General charges per cent. on gross receipts	$2\frac{9}{10}$
Taxation per cent. on gross receipts	$7\frac{1}{2}$
Average receipts per train per mile, exclusive of cartage	7*s.* 7*d.*
Total expenditure per train per mile	3*s.* 5*d.*
Total expenditure per cent. on gross receipts	$43\frac{3}{10}$

It would appear also, from an average obtained from the returns of the principal Railway Companies, that 43 per cent. is about the proportion of the expenditure to the gross receipts in this country, whilst the average return on the capital has been stated to be 3·4 per cent. From a return of railways in Prussia, Austria, Saxony, and Bavaria, it would appear that the expenses of working, in 1848, were 58·46 per cent. of the gross receipts, and the return on the capital expended 3·19 per cent. From the half-yearly return of traffic on railways published by Government, it appears that the proportion of goods to passenger traffic is continually on the increase.

It may be as well to mention in this place, that the rapidity of transport between two places by train on a railway will depend more upon the number of intermediate stoppages than upon the speed maintained by the train whilst in motion ; since each stoppage may be considered to consume five minutes, viz. : $1\frac{1}{2}$ minute for the train to come to rest, $1\frac{1}{2}$ minute to start, and 2 minutes to remain at the station.

Fares.—The fares which the public have to pay on railways may be divided into two parts ; the first being what a Company constructing a line would charge as a toll upon the passengers and merchandise using it, and would be made up of a sum for interest on the capital expended in the construction of the line, the cost of maintenance, and of police. The second is, what a Company working the line would charge, and is made up of the actual cost of conveyance, the interest on the working stock, and the charges for superintendents, clerks, porters, &c. The proprietors of a railway will always be able to carry at a lower rate than any one else upon their own line under a fixed system of tolls, because any receipts beyond the mere cost of conveyance

and maintenance would be a profit; whilst other persons using the line would have to pay, under the head of toll, a fixed interest on the capital employed in the construction.

In fixing the sums to be charged, therefore, it is necessary to obtain an approximate estimate of the number of passengers, and the quantities of merchandise to be expected on a railway,—assuming, in the first case, a certain number of trains per day for the cost of locomotive power;—and in estimating the price per ton to be charged for merchandise, the gross amount would be divided by what would constitute an average load,—the classes of goods, cattle, &c., being obtained from an assumed bulk per ton.

Traffic.—The first point to be considered in estimating the probable traffic on a railway is the size of the district which will employ the line as a means of conveyance. In a wealthy and a mercantile community, where time is of more value than money, the most rapid mode of conveyance will be preferred; whilst in a poor country, and for the carriage of goods, the railway will only be adopted when its use will insure diminished expense; or, in other words, the limit for the probable contingent traffic of a railway will be the point at which the land carriage to the line, together with the conveyance upon it, can be effected in less time or at less expense than the other available land carriage for the whole distance. It must, however, be borne in mind that the land carriage to the line should be estimated along the main roads leading to the nearest station, and that for short distances the inconvenience of changing carriages, and the delay, will often more than counterbalance the advantages to be derived from using the line; and hence, for the full development of local traffic, rigid punctuality in the arrival and departure of trains is of more importance than appears to be generally understood.

In estimating the passenger traffic, it may be assumed that the intercourse between different places would vary as the product of the population, and according to some law of the distance, all other circumstances of population and rate or speed of conveyance being the same. The law of the distance would of course depend upon the habits, pursuits, and wealth of the population; and a fair value for each description of population could only be obtained from a number of general averages. It is to be regretted that Railway Companies do not publish, in their half-yearly returns of traffic, the numbers of passengers between the several stations on their lines. The only returns of the sort which have been published were by the South Eastern Company, for the year 1845, in a Report to a Committee of the House of Commons on Railway Acts Enactments, in 1846; and although that line is almost the worst which could have been selected, both from being the main road between London and the Continent, and because the agricultural population through which it passes is not concentrated about the stations along the line,—and therefore the results cannot be relied on as correct co-efficients for the distances,—yet they will exhibit the effect which distance has in rapidly diminishing the per-centage of the population which travels. The average co-efficients for an annual traffic which have been obtained are as follows:

For a distance of about		6 miles,		$\frac{1}{800}$
,,	,,	10	,,	$\frac{1}{2500}$
,,	,,	15	,,	$\frac{1}{4000}$
,,	,,	20	,,	$\frac{1}{12000}$
,,	,,	30	,,	$\frac{1}{18000}$
,,	,,	40	,,	$\frac{1}{50000}$
,,	,,	50	,,	$\frac{1}{70000}$
,,	,,	60	,,	$\frac{1}{90000}$

In framing estimates based upon similar data, it is necessary to recollect, that whilst towns which are situated on the line should have their population reckoned at the full value, those towns situated at a distance from the line, and agricultural districts, may be considered as towns of a proportionately smaller amount of population concentrated at the stations.

The fact to be inferred from the above, viz. that the great mass of passengers consists of those who travel short distances, is further confirmed from the result of traffic returns in Great Britain for the last six months of 1848, shewn in the first column of the following Table; and the result given is in accordance also with what might be presupposed, viz. that the poorer classes would avail themselves of railways for short distances, more than those classes who possess other means of locomotion. From the results stated in the second and third columns, it would appear that the inferior classes of passengers form the chief source of railway business.

	Average distance travelled by each passenger.	Per-centage of each class booked on the number.	Per-centage of each class on miles travelled.
1st Class .	27·0	19·3	11·8
2nd Class .	16·5	38·5	38·6
3rd Class .	14·0	42·2	49·6
Average .	16·5	Total 100·0	Total 100·0

Where there are no competing facilities on either side of a railway, and no natural barriers to impede the traffic, it may be assumed that the probable amount of merchandise which would be conveyed upon a railway would be the whole surplus produce of the district through which the line would pass, together with the imports which would be required for the consumption of the population of the district, as well as part of the surplus produce, and of the imports for consumption of such other parts of the country as would find it advantageous to use the line as a medium of communication. There are no official documents from which, for this country, the transmission of different descriptions of produce from one part of the country to another can be judged of; and it would be beyond the limits of the present article to describe the modes which have been adopted to obtain it.

It may, however, be curious to observe, that it has been estimated that the average distance travelled on railways for each unit booked is, for

Merchandise, tons	$22\frac{1}{2}$ miles.
Cattle, number	$30\frac{1}{3}$,,
Sheep, do.	$32\frac{2}{3}$,,
Pigs and Calves, do. . . .	$55\frac{3}{8}$,,

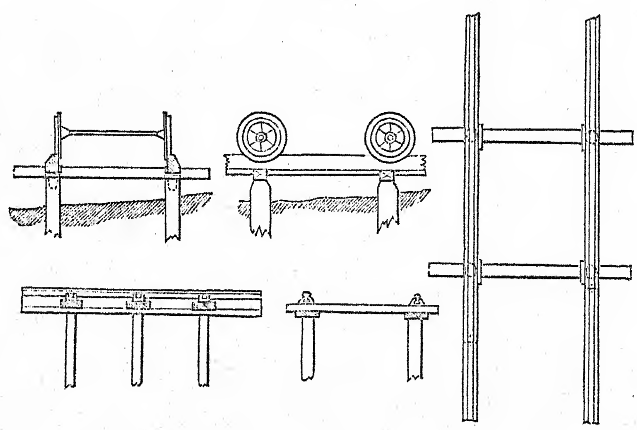
and that whilst in a period of six years and a half the passenger traffic on railways only increased 28 per cent., the goods traffic was augmented 282 per cent.

The principal points to be attended to in working a railway are to obtain a maximum daily mileage from the engines, combined with a maximum effective load in the trains; and since the terminal expenses for goods traffic are comparatively heavy, it should be remembered that the greater the distance the goods are conveyed, the smaller will be the proportionate expense.

American Railways.—Having now stated the general principles upon which railways are constructed and worked, more particularly in this country, it is proposed to add a few remarks on the cheaper arrangements which have been adopted in

America. In that country railways have been constructed at an expense of from £8000 to £9000 per mile. The country they pass through is generally level, requiring low embankments and shallow cuttings. The bridges are of timber from the adjacent forest (occasionally with stone abutments and piers), and frequently the stations, offices, and other buildings are also of timber. From the comparatively limited amount of traffic conveyed upon them, a single line, with sidings at intervals, frequently suffices at first; and should a double line be required, it can be added from the profits. The lightness of the traffic and the moderate speed, viz. 14 or 15 miles per hour, have permitted a more economical roadway than that in use in this country; the curves are frequently of 7 chains radius,—curves of 15 chains radius are usual; and gradients of 1 in 75 are numerous. In some instances, under peculiar circumstances, and where timber was abundant, pile lines, as shewn in the accompanying sketch, have been constructed; where high above the ground, diagonal braces have to be introduced so as to form trestles: instances are, however, stated to

Fig. 18.



have occurred, where these viaducts have warped, and let the engine slip down between the rails. In consequence of the cheapness of wood, and the high price of iron, light rails, laid on longitudinal bearers, are used, which are supported by cross bearers, 5 feet apart. When the traffic is light, the longitudinal timber of hard wood sometimes forms the rail, having its edge protected from splitting by a plate of iron let into it and spiked down, $2\frac{1}{2}$ in. broad and $\frac{1}{2}$ in. deep. This plate, however, when so fixed, is liable to rise up at the end, and to *snag* the engine; and rails similar to those in this country, but with the sleepers at shorter intervals, to admit of a lighter rail, viz. from 25 to 30 lbs. per yard, are in general use. When increased traffic is anticipated, the earthworks, &c. are constructed for a double line.

The speed on these lines, stoppages included, is 14 or 15 miles per hour; and the fuel in ordinary use is wood (except in the coal districts, where coal is used), from its cheapness, and from the smoke not being objected to in a thinly-peopled country. The carriages are only adapted to carry one class of passengers, except that a compartment is set apart for people of colour: they are of great length, with a passage down the middle, on each side of which are seats placed crosswise, and

there are doors at either end. Each carriage accommodates from 60 to 80 passengers. To enable these carriages to move round curves, instead of resting directly on the axles, each end rests on a four-wheeled railway-truck, to which it is attached by a pivot. Railways are frequently carried to the centres of the towns, along the sides of the streets; the train for the latter part of the journey being drawn by horses. In the parts of the country exposed to snow, and where it is liable to fall to a great depth, it is considered advisable, in order to obviate as much as possible the probability of interruption from this cause, to keep the rail to the height of the average depth of the snow in the country. In order to clear lines from snow, snow-ploughs are used. In a double line the ploughshare lies over the inner rail, and throws the snow outwards,—first clearing one track and returning by the other; whilst for a single line the ploughshare travels along the centre of the track.

Railways have been constructed in America, as in this country, by joint-stock companies,—the State, however, reserving to itself considerable powers. But Companies are not exposed to the same preliminary difficulties that they are subjected to in this country and in France. The time for the completion of the works is limited under pain of forfeiture, and the traffic in shares before the Company is definitely formed is prohibited.

Comparative Cost of Railways.—The following is the cost per mile of railways in the subjoined countries, vix.

Austria	£12,000	Belgium	£16,200
Prussia	11,100	France	21,300
Rest of Germany .	11,200	Great Britain . .	27,000
Whole of Germany .	11,300	United States . .	8,200

The following are works which give information on the subject of this article, and of which some use has been made in its compilation, viz.

The Practical Railway Engineer, by Drysdale Dempsey, Esq. C.E.
Baker's Railway Engineering.
Haskoll's Assistant Engineer's Railway Guide.
Bidder's Tables.
Macneill's Tables.
Huntington's Tables.
Seguin, Chemins de Fer.
Belpaire, sur les Dépenses d'Exploitation.
Lardner's Railway Economy.
De Pambour on Locomotives.
Weale's Tredgold on the Steam Engine.
Report of Commissioners on Railway Communication in Ireland.
Gauge Commissioners' Report.
Reports of the Commissioners of Railways.
Report of Railway Commissioners on Railway Communication between London and Birmingham.

Note by Editor. In addition to the points already mentioned, the following matters may be here noticed as essential or at least very important. The establishment of some easily available means of communication between the engine driver and guard, and between the latter and the passengers, so that anything wrong may at once be known and evil prevented. The arrangement of a secure pathway for the guard throughout the length of the train, either through the middle or along the outside of the carriages. There seems to be no doubt also that loss of life and property might have been on several occasions avoided during inclement weather, had the engine driver and fireman been protected by any kind of shed or cover on the engine; which, while sheltering them from the driving wind or rain, might yet not interfere with a good look out. This might be readily accomplished as in the United States, by having the shed on a platform behind the fire, covered over the top, open towards the tender, and

glazed on the front and sides with clear strong glass, so as to allow perfectly clear vision; and even apart from the question of safety, the health and usefulness of the men are of such importance, that no question of expense ought to be allowed to interfere with making provision for their protection. Mirrors might also be placed at such an angle on each side, that the whole length of the train should be visible, and any signal made either by flag or lamp for day or night, might be at once seen and responded to.

RECONNOITRING.

MILITARY RECONNAISSANCE OF A TRACT OF COUNTRY OR OF A POSITION.

The mode of obtaining the information required relative to any portion of ground, must of course vary according to circumstances; for instance, if it is occupied by an enemy, great judgment, celerity, and daring will be required to procure any, whilst, if that is not the case, the examination of it may be carried on more deliberately and thoroughly, omitting nothing which is likely to be of use in enabling a General to make arrangements for moving troops through it, for quartering them at different points, and for carrying on offensive or defensive operations in every part of it; and as these may prove very disastrous if based on false information, the greatest care must be taken to write down the results of the observations soon after they are made, and so distinctly as to prevent the possibility of mistakes arising.

It is usually effected, if in presence of an enemy, by a few mounted officers, each protected by a small party of cavalry, and accompanied by some of the inhabitants as guides; the escorts may, however, often be dispensed with, so as not to attract so much observation, and grey cloaks should be worn for the same reason; but an uniform must be worn underneath, to prevent their being considered as *spies*, if taken. They should start for this purpose after dusk, so as to conceal, if possible, their intentions: to avoid being stopped by the enemy they should not travel far along the main roads, but must *cross* them as often as possible to examine their character: they should never halt long, except at single houses apart from the villages, and never sleep on two successive nights at the same place: they must avoid giving a clue to their intended route or object by their inquiries, or by letting their guides see them taking angles and drawing plans; and they must also be provided with two or three days' rations, to prevent the necessity for going into any houses whatever when there is danger of being taken prisoners.

A *map* of the country is usually required to be constructed; or at least, if there is not time or means for constructing one, as explained in the article on 'Field Sketching,' a rough diagram must be made to show the positions of the principal points, and of the rivers, mountains, forests, roads, &c.

A *memoir** or *report* is indispensable, to give an account of the features of the country and of the positions held by the enemy, and should be accompanied by an alphabetical list of the various places in a tabular form, so as to show at a glance the resources and accommodation afforded at each.

Memoirs must be prepared with great care and consideration, and afford the means of judging of the capacity of the writers, not only for observing, but for placing the

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* See article on "Reports," in this volume, p. 256.

results of their observations clearly before the reader, who ought to be able at once to find the general description of any particular part of the country, as well as all details if he requires them. The latter may sometimes be conveniently placed in a tabular appendix, reference being made to them in the report itself, which may thus be condensed. A table of contents must be prefixed to the memoir, and such an arrangement of the subjects must be made as to enable any one of them to be found immediately.

The style should be concise, but the information afforded must be as complete as the circumstances of the case require, care being taken to avoid digressions about irrelevant or unimportant matters, and to keep the principal points prominently in view. It may also be observed that reports have sometimes proved nearly useless from the badness of the writing, and that great care must be taken to spell the names of places, &c. correctly, to give all the names by which they are known, and to write them so that there can be no mistake with regard to those which are nearly alike. It is very desirable that officers employed in reconnoitring should have a good knowledge of the language of the inhabitants of the country to be examined.

The following Orders, given by Sir George Murray to the Officers of the Quarter-Master-General's Department during the Peninsular War, will serve as a guide in the compilation of reports, and the table must shew in separate columns the number of men and horses for which there is permanent and temporary accommodation, the quantities of various kinds of cattle, carriages, food, fuel, and other resources available, and the number of mechanics, mills, forges, &c.

"One of the first duties of the Officers of the Quarter-Master-General's Department is to acquire a knowledge of the country which is the theatre of the operations of the army: this supposes not only an acquaintance with the natural and political divisions of the country, and with its principal features, but also detailed local information on the following points:—

"1st. The peculiar nature of each district of country and its productions; what parts of it are mountainous or hilly, and what are level; whether the hills are steep or broken by rocks, or if they rise by gradual and easy slopes, or if the ground is undulated only in gentle swells; whether the connection of the high grounds is obvious and continued, or if the heights appear detached from each other; in what direction the ridges run, and which is their steepest side; what is the nature and extent of the valleys, and, in like manner, what is the nature of the ravines,—where they originate, in what directions they run, and whether they are of difficult access or to be easily passed.

"Whether the country is barren or cultivated, and what is the kind of cultivation,—whether vines, olives, or corn (and, if the latter, what kind,) are grown, and in what parts they are most abundant; also what is the nature of the soil.

"If it is a country of pasturage, whether it is pastured by cattle, by sheep, or by horses, and in what numbers.

"What parts of the country are open and what are enclosed; also the description of the enclosures, whether small or extensive, formed of stone walls, ditches, hedges, or fences of any other kind.

"What parts of the country are wooded, and whether with full-grown timber or coppice-wood, also with what species of trees.

"What is the nature of the country with reference to the operations of troops; what parts are favourable to the action of Cavalry, and what for Infantry only.*

* It must not be forgotten that the facilities for moving troops are often much affected by the seasons, by rains, and by frost.

2nd. *The Rivers, lesser Streams, and Canals.*—The sources of rivers and the direction of their course,—whether they are rapid or otherwise; their breadth and depth, and what variations they are subject to at various seasons of the year; the nature of their channels and banks,—whether rocky, gravelly, sandy, or muddy, of easy or of difficult access: the bridges across them,—whether of stone or of wood; their breadth and length, and whether accessible to Artillery, and capable of bearing its weight.—The Fords, with similar remarks, and whether always passable, or at certain times and seasons only.*—Which rivers are navigable, from and to what points, and by what description of vessels or boats.—The Ferries, their breadth and the nature of the landing-place on each side; what description of boats is used upon them; how many men, horses, carriages, &c., each boat is capable of containing,—how much time the passage requires, and in what manner it is performed.—Canals, their course, breadth, and depth; the nature of the traffic carried on upon them; the number of boats usually to be found at different places, and their nature and dimensions; also, whether they are tracked by men or horses, or how otherwise navigated.—Lakes and inlets of the sea, their situation, extent, and boundaries; what description of vessels can navigate them, &c., together with such of the above observations as are applicable to them.—Marshes, their situation and extent; whether passable for troops in any part, and whether they continue wet throughout the year, or exist only during the wet season.

"3rd. *Population, resources, accommodation for troops, &c.*—The size of towns and villages, and the number of their inhabitants; also whether they are well supplied with provisions or not; the number of houses, churches, convents, or other public buildings; whether the houses are large and commodious, or small and mean; what number of troops could be accommodated in private houses, and what in public buildings: what stabling or other cover there is for horses; whether the towns are walled or open, favourably situated for defence or otherwise, also if capable of being strengthened, and by what means. Similar observations in regard to detached convents, gentlemen's seats, farms or other separate buildings, are required; and plans or sketches of walled towns, defensible villages, or detached buildings, should always accompany the reports upon them.

"The number of carriages, horses, mules, or draught oxen, in possession of each town, village, or farm, should be stated, and what is the general means of conveyance made use of in the country; whether places are unhealthy or not; and if they are, whether there are any obvious local causes; also, whether they are generally unhealthy, or only so at particular seasons.

"4th. *Roads.*—Particular information must be obtained respecting roads, in the description of which it is impossible to be too minute: the general nature of each road, and also all variations which occur in it from distance to distance, should be accurately described; whether the road has been regularly made, or appears to have been formed only by the use of the people of the country; whether it is fit for Artillery, or practicable for any description of wheel-carriages, for Cavalry or for Infantry only; over what description of soil it passes, whether rocky or gravelly, sandy, clayey, or earthy, and to what injuries it is liable in bad weather; whether it is easily repairable or not; what materials are requisite for that purpose, and whether they are to be found in the neighbourhood; whether any bad parts of the road, or the narrow and embarrassed streets of any of the towns or villages, can be avoided by

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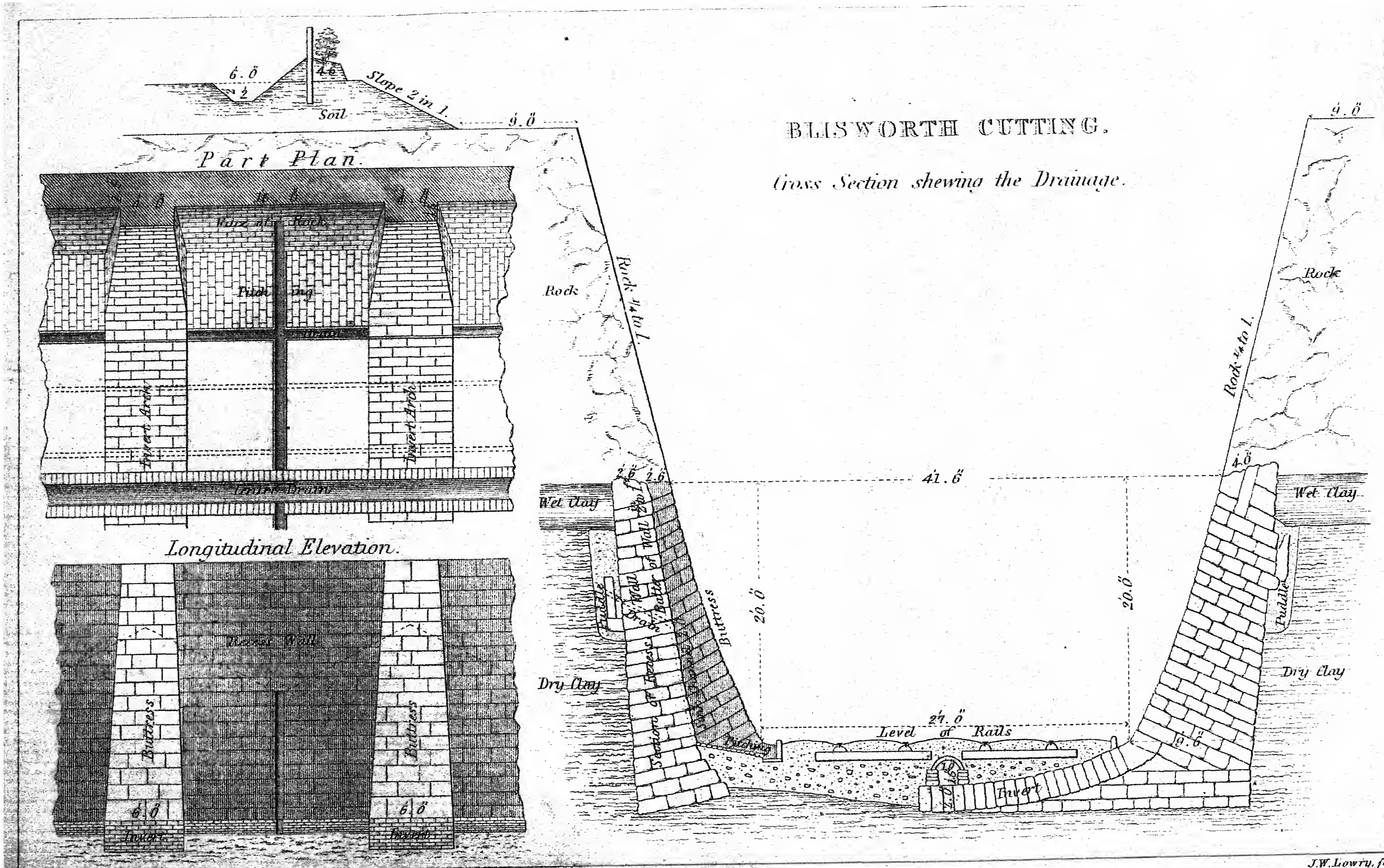
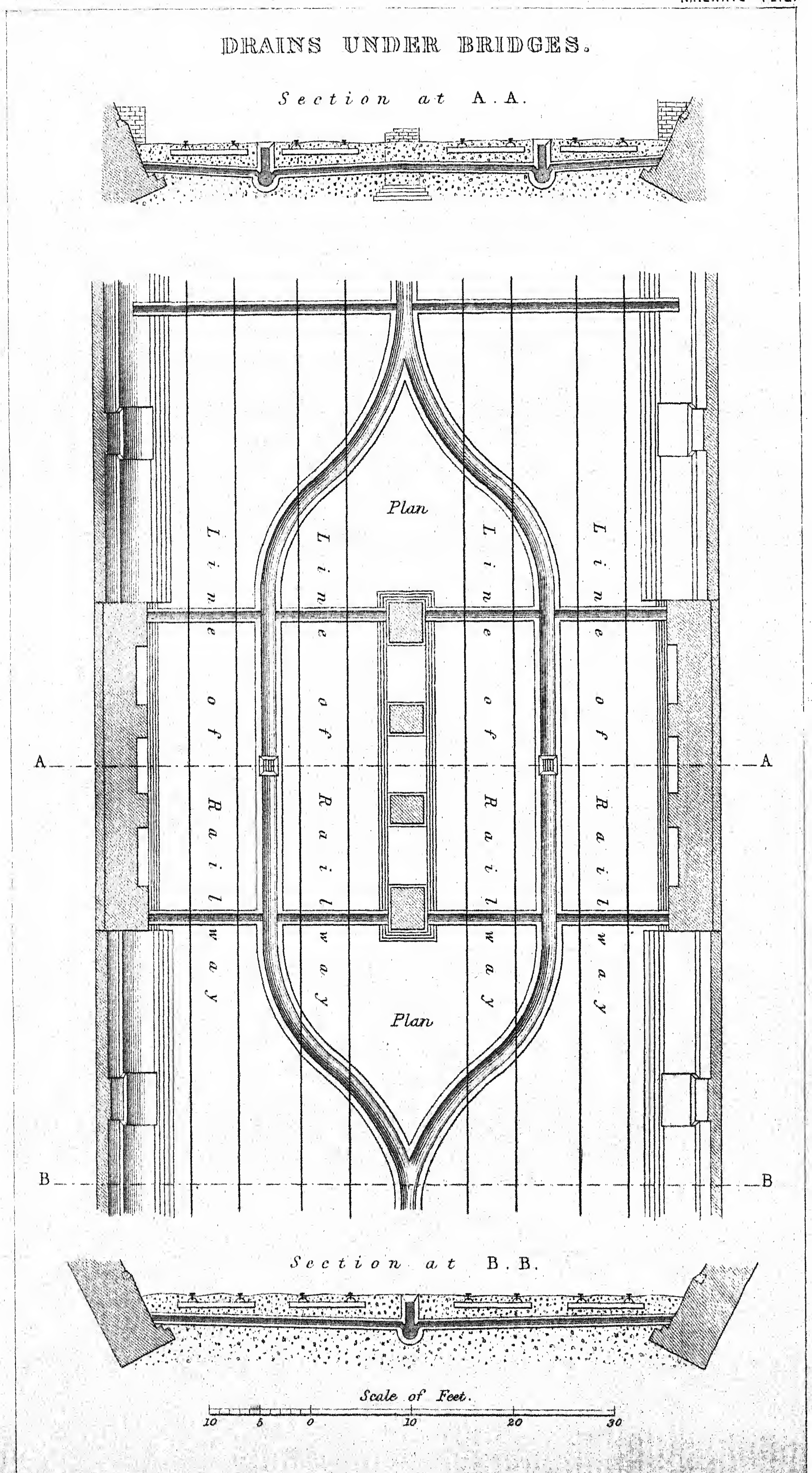
* See article "Fords," vol. i. p. 545.

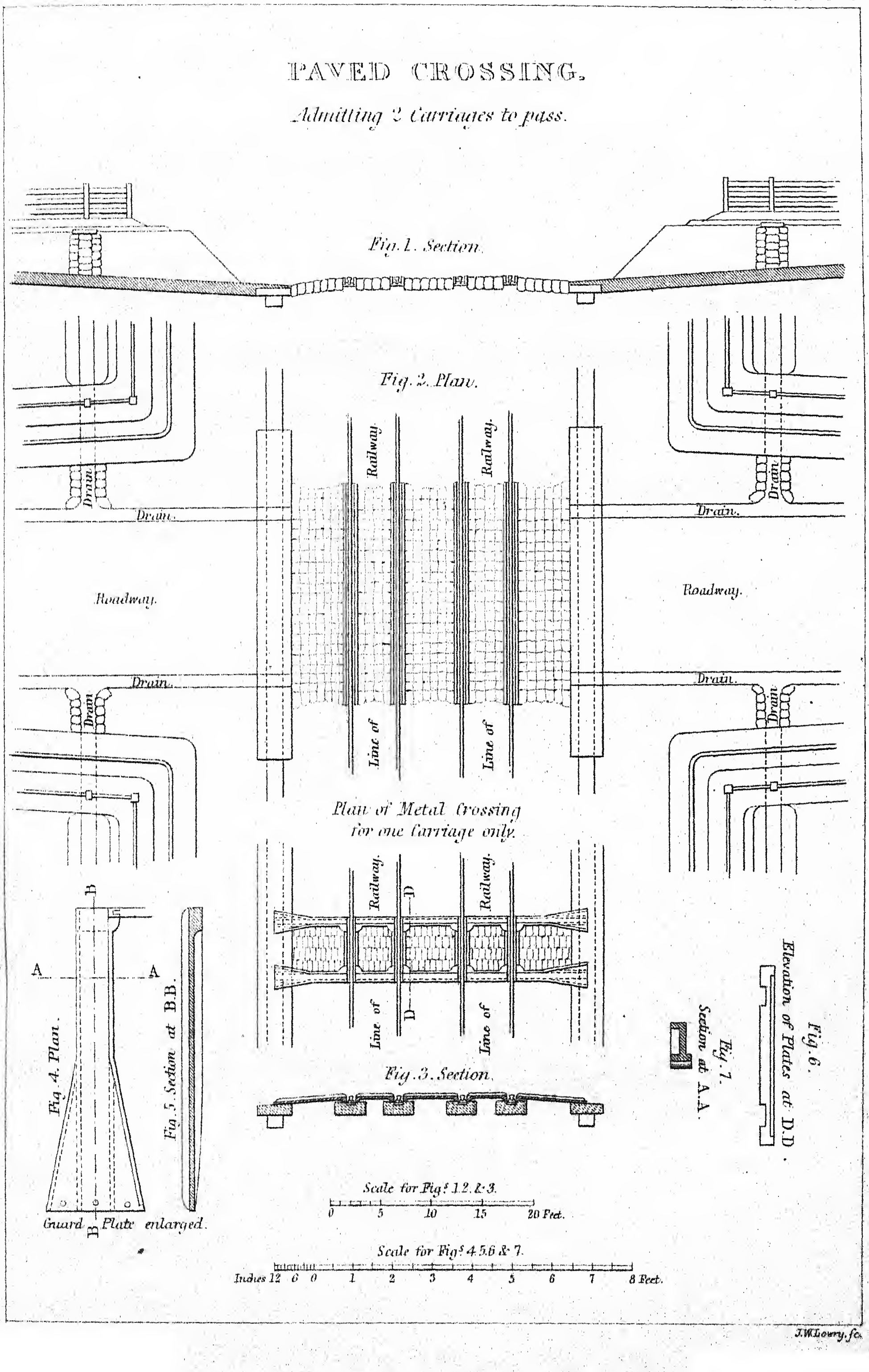


London, Lockwood & Co. 7, Stationers Hall Court, Ludgate Hill, 1860.



London: Lockwood & Co. 7 Stationers' Hall Court, Ludgate Hill; 1860.

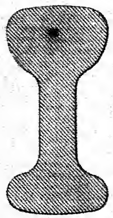
J. W. Lowry Sc.



London: Lockwood & Co. 7 Stationers' Hall Court, Ludgate Hill, 1860.

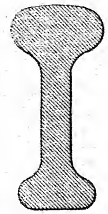
SECTIONS OF RAILS USED ON TRANSVERSE SLEEPERS.

85 lbs. Rail.



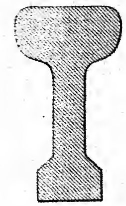
London & North Western (Huddersfied & Manchester Line.)
Lancashire & Yorkshire (West Riding Union &c. (81 lbs.)
Edinburgh & Northern (75 lbs.)
Cork & Bandon (70 lbs.)
Lancashire & Yorkshire (Burnley Branch (82 lbs.)
D°. .... D°. ...... (Ardwick Branch (82 lbs.)

66 lbs. Rail.



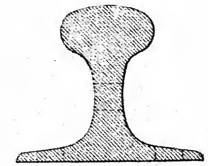
Norwich & Brandon.
Eastern Counties (Enfield & Edmonton.)
D°. .... D°. ...... (Cambridge & S^t. Ives.)

60 & 65 lbs. Rail.



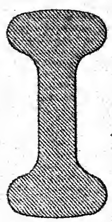
Great North of England.
(Boroughbridge Br.)

67 lbs. Rail.



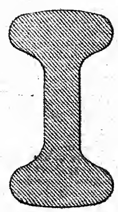
Coleford, Monmouth, Usk & Pontipool.
Cork & Youghal. (64 lbs.)

80 lbs. Rail.



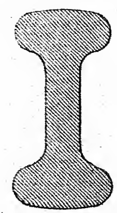
Windsor, Staines & South Western Railway.
London & South Western (Hampton Court Br.)
South Eastern (North Kent Line.)
Reading, Guildford, & Reigate Railway.

75 lbs. Rail.



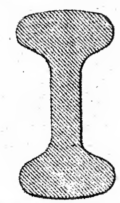
Caledonian Railway.
Eastern Union Railway.
Edinburgh & Bathgate Railway.
North British (Harwich Branch.)
Scottish Central Railway.
Eastern Counties Extension (76 lbs.)
London & Brighton (Eastbourn & Hailsham Br.)

71 lbs. Rail.



Liverpool, Ormskirk & Preston (74 lbs.)
North Staffordshire Railway. (72 lbs.)
Waterford & Limerick Railway. (71 lbs.)
Lancashire & Yorkshire (Ardwich Branch (68 lbs.)

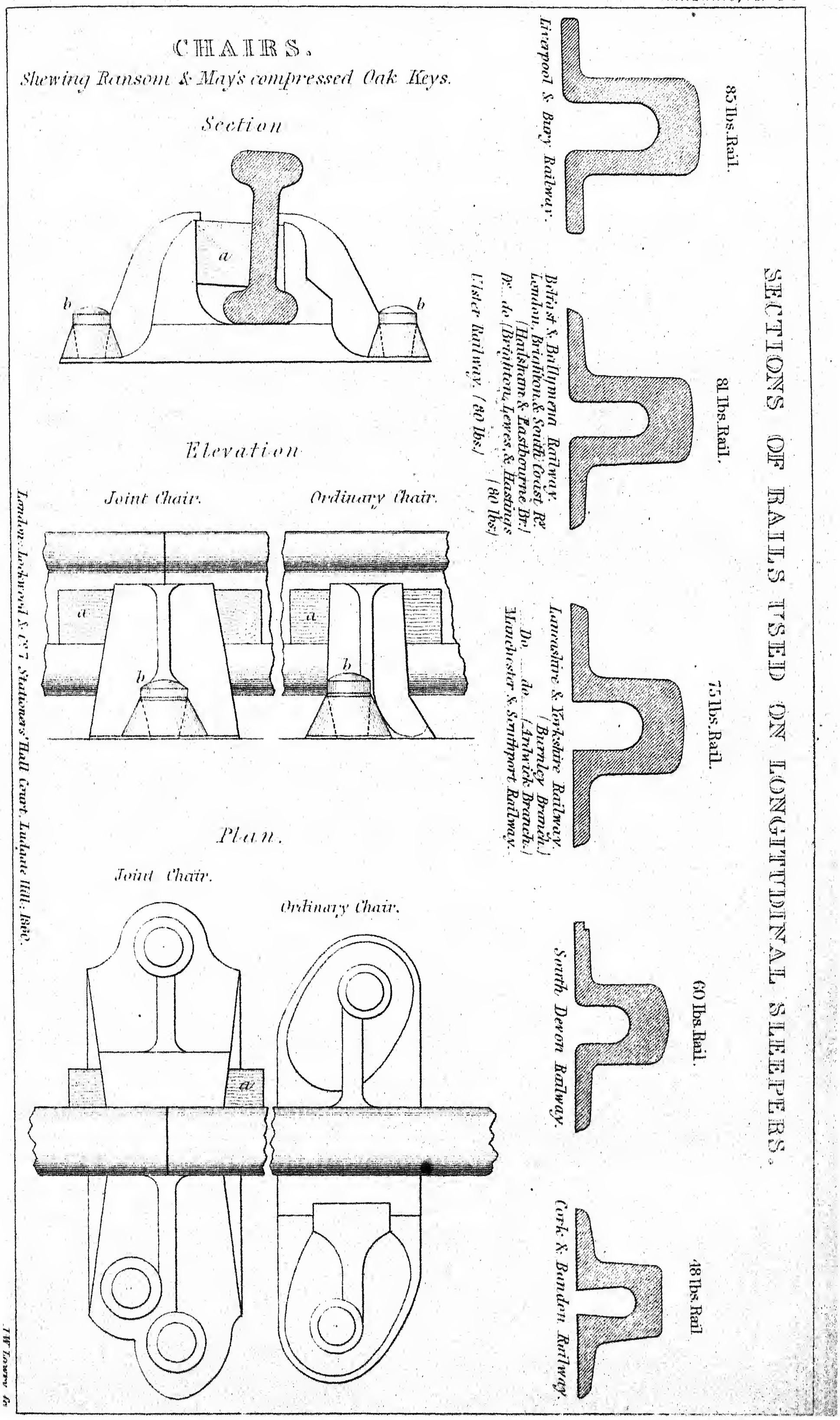
65 lbs. Rail.

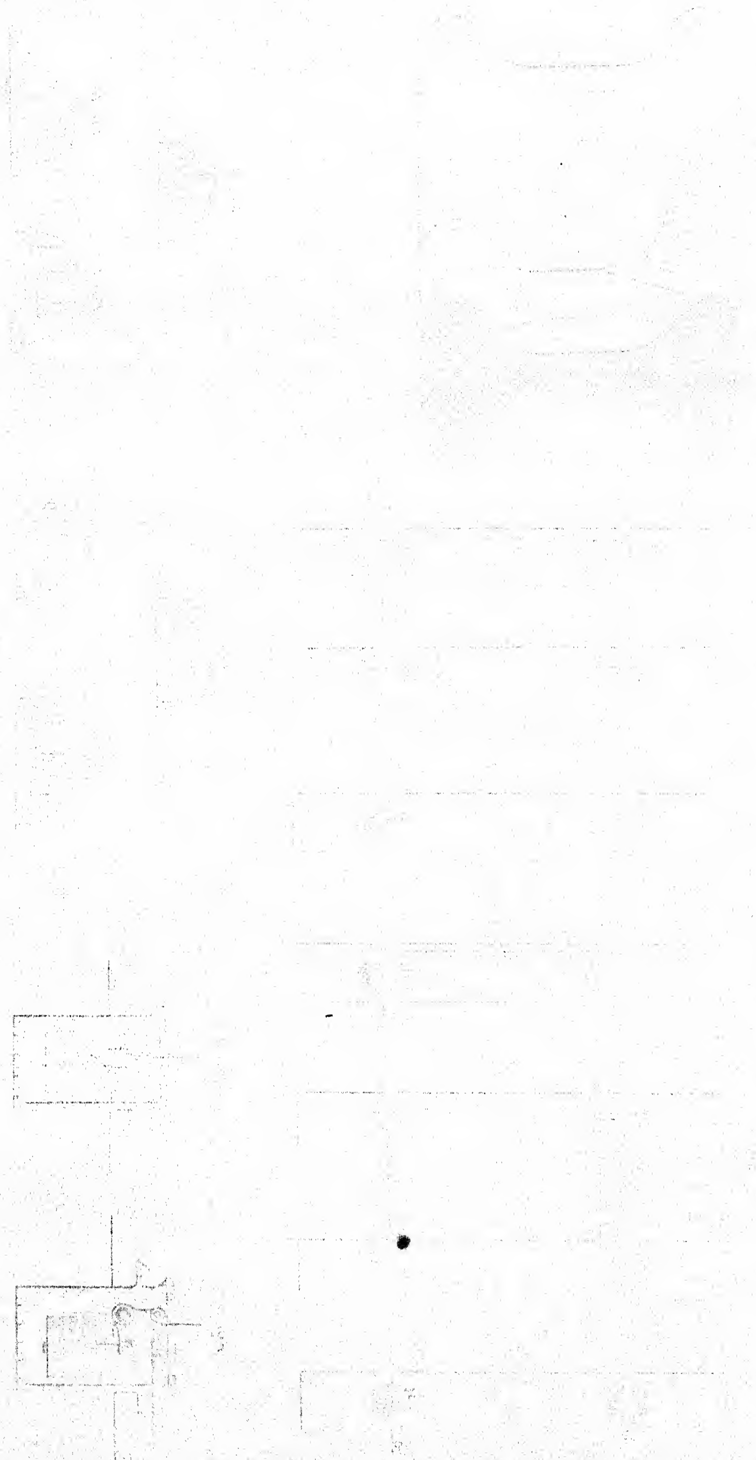


Aberdeen Railway.
Arbroath & Forfar Railway.

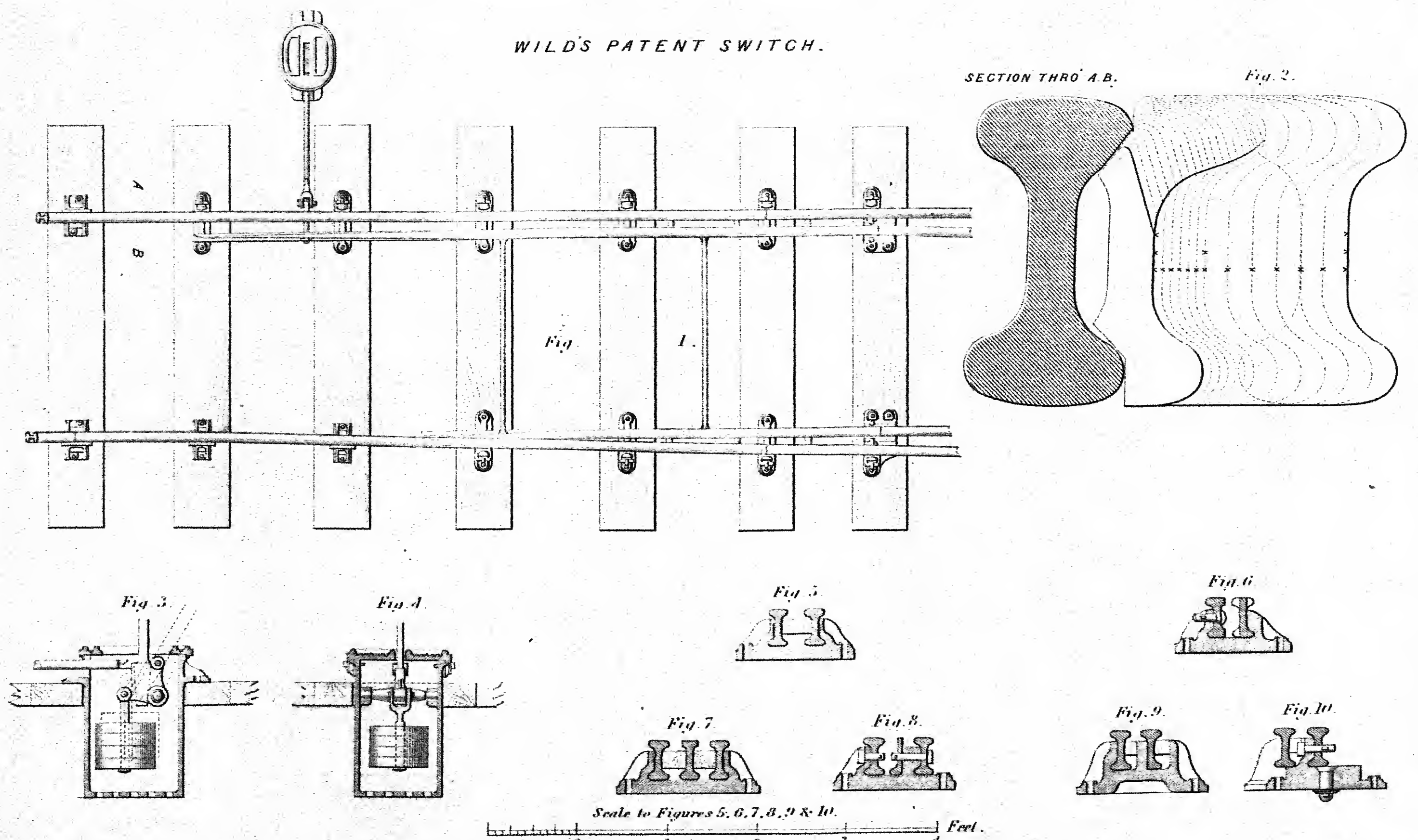
London, Lockwood & C°. 7, Stationers' Hall Court, Ludgate Hill; 1860.

J.W. Lowry fc.


CHAIRS.
Shewing Ransom & May's compressed Oak Keys.
Section
a
b
b
Elevation
Joint Chair.
Ordinary Chair.
a
a
b
b
Plan.
Joint Chair.
Ordinary Chair.
a
London: Lockwood & Co. Stationers' Hall Court, Ludgate Hill: 1860.
SECTIONS OF RAILS USED ON LONGITUDINAL SLEEPERS.
85 lbs. Rail.
Liverpool & Bury Railway.
81 lbs. Rail.
Belfast & Ballymena Railway.
London, Brighton & South Coast Ry.
(Hailsham & Eastbourne Br.)
Do. do. (Brighton, Lewes, & Hastings (80 lbs.)
Ulster Railway. (80 lbs.)
75 lbs. Rail.
Lancashire & Yorkshire Railway.
(Burnley Branch.)
Do. do. (Ardwick Branch.)
Manchester & Southport Railway.
60 lbs. Rail.
South Devon Railway.
48 lbs. Rail.
Cork & Bandon Railway.



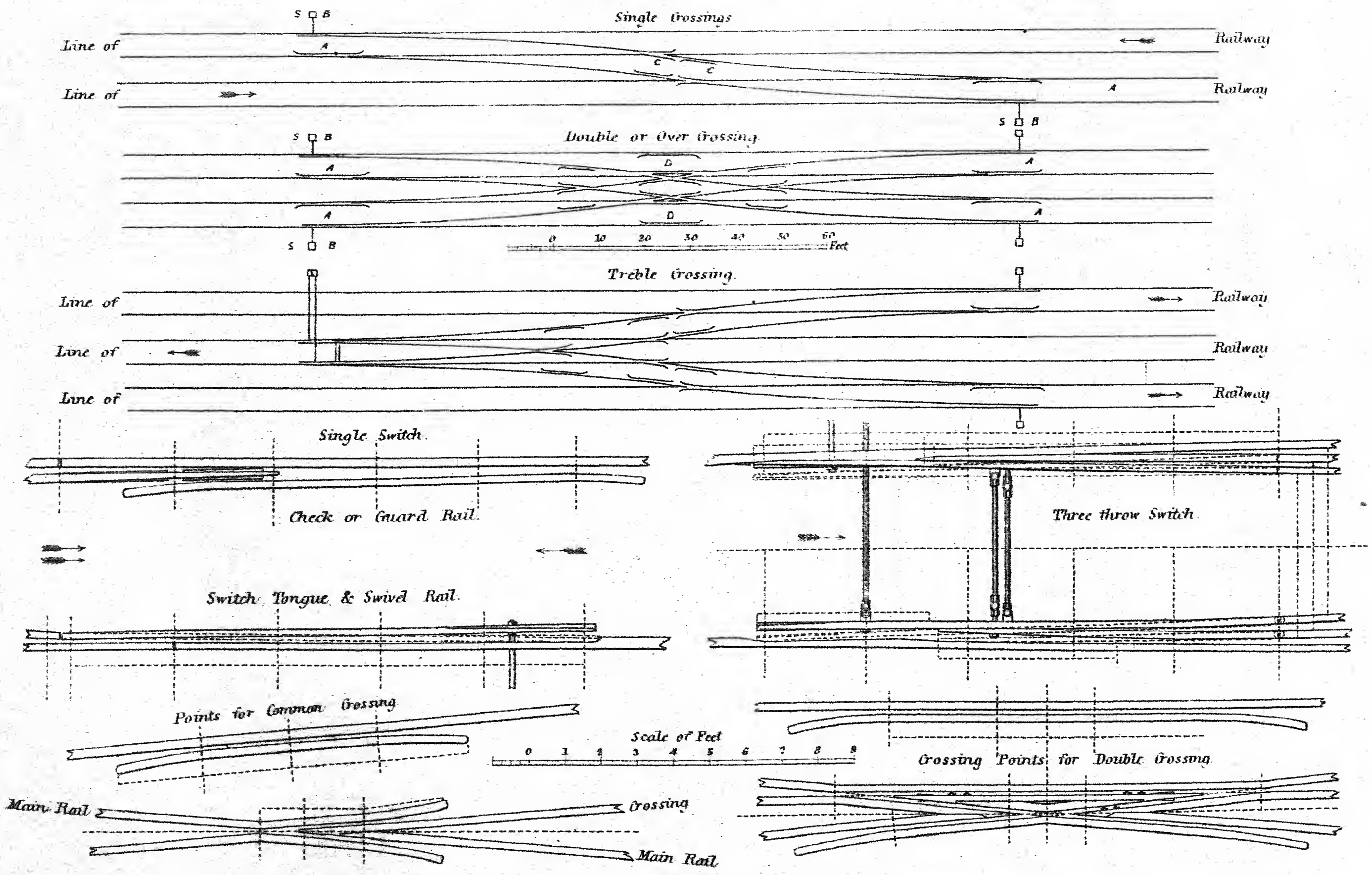
WILD'S PATENT SWITCH.



W. A. Beever, Sc.

London: Lockwood & Cº. 7 Stationers' Hall Court, Ludgate Hill; 1860.

CROSSINGS,



J. W. Lowry, fc.

London: Lockwood & Cº, 7 Stationers' Hall Court, Ludgate Hill: 1860.

DUNN'S TURNTABLE.

Fig. 1.

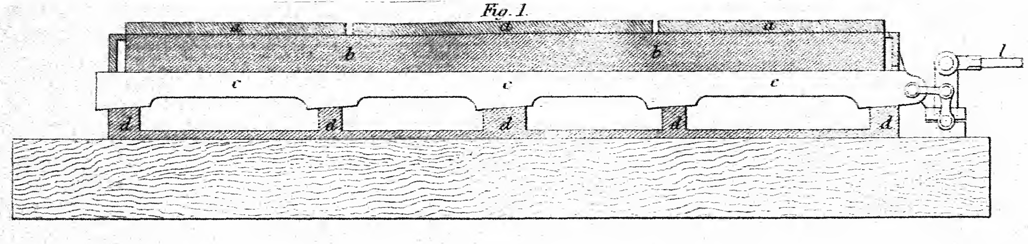
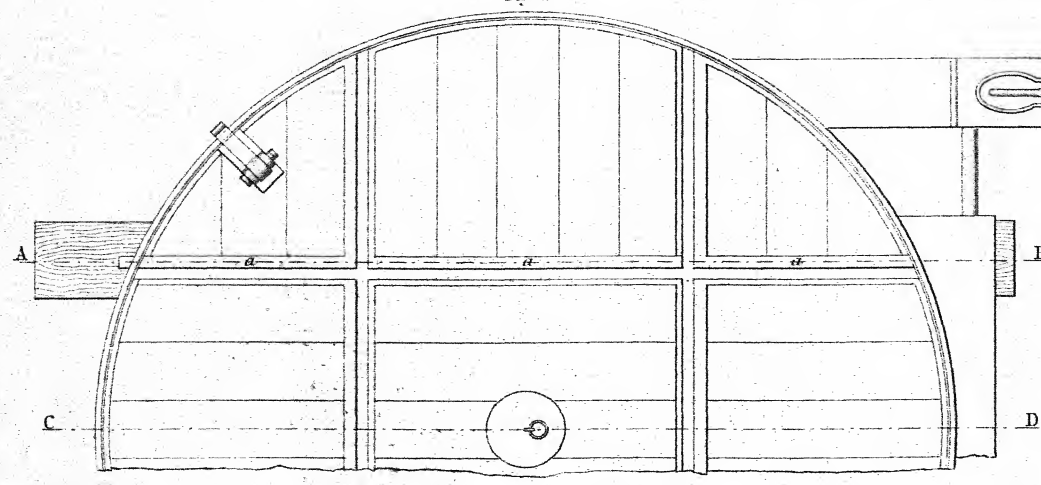


Fig. 2.



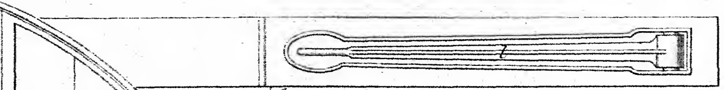


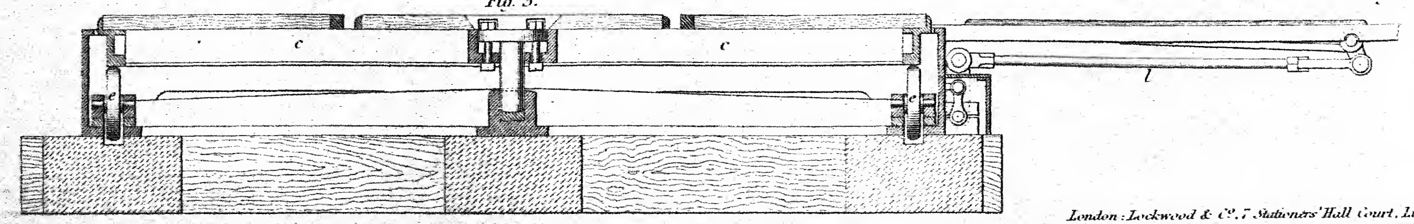
Fig. 1. Is a Section of the Turntable through the line A.B. shown in Fig. 2.

Fig. 2. Is a part in Plan of the Turntable top.

Fig. 3. Is a Section of the Turntable through the line C.D. shown in Fig. 2.

In Fig. 1. a.a. Is a Section of Rail on the Main Line of Way.
b.b. Is the Girder upon which the Rail is fixed.
c.c. Is a sliding Beam the top surface of which is planed, so that by the lever l. and the wedge shaped bearings d.d. this sliding beam may be raised in contact with the under and planed side of the girders b.b. whereby the Platform is made rigid. When the Platform is required to be turned the sliding Beam is lowered by the lever l. and the platform is left to turn upon the friction pulleys e.e. two of which are shown in Fig. 3.

Fig. 3.

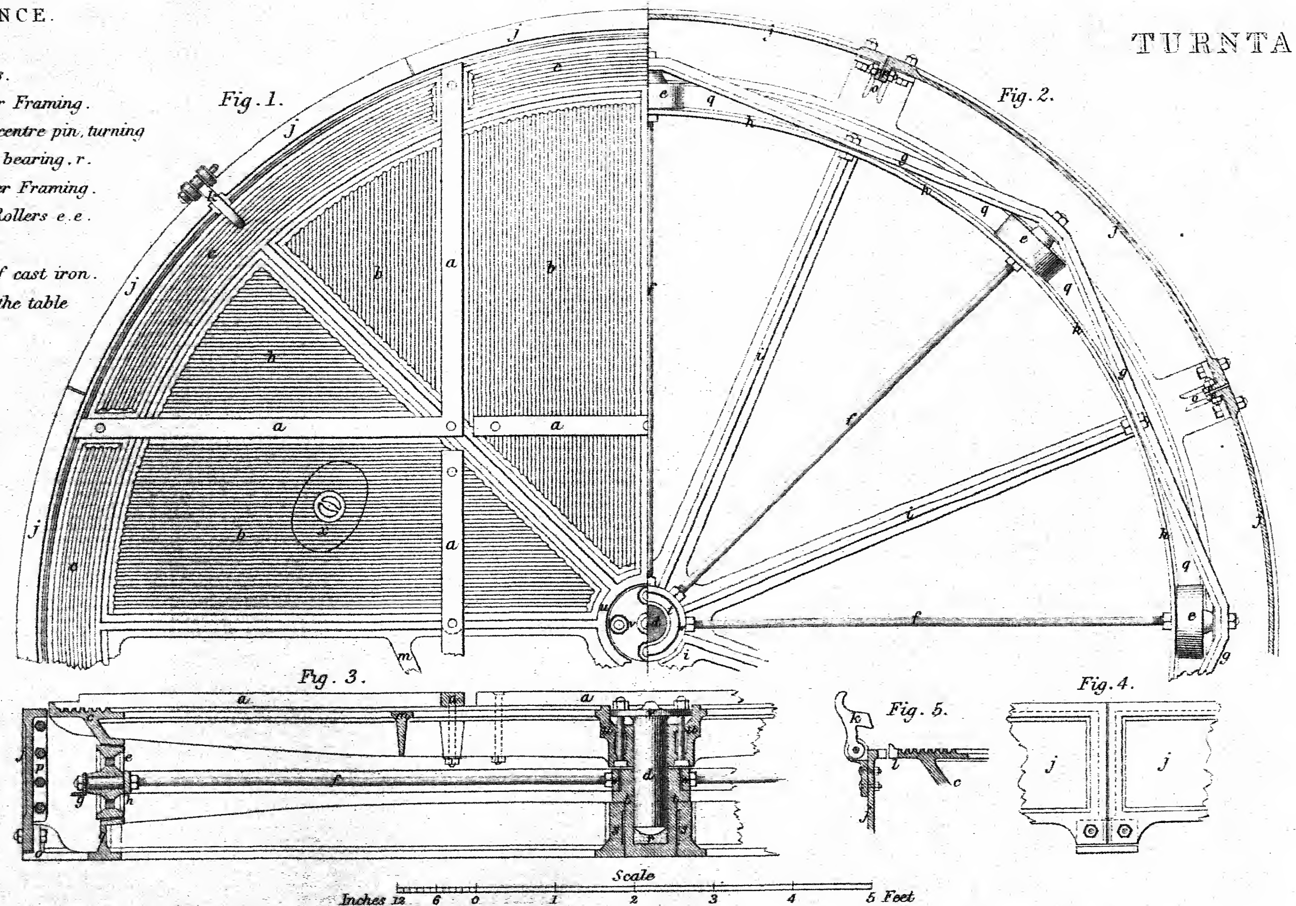


London: Lockwood & C°. 7 Stationers' Hall Court, Ludgate Hill, 1862.

TURNTABLE.

REFERENCE.

a. Rails.
b. Covering Plates.
c.m. Cast iron upper Framing.
d. Wrought iron centre pin, turning on gun metal bearing, r.
i.q.s. Cast iron lower Framing.
f. Rods to hold Rollers e.e. in place.
j.j. Outer Casing of cast iron.
k. Latch to keep the table in position.



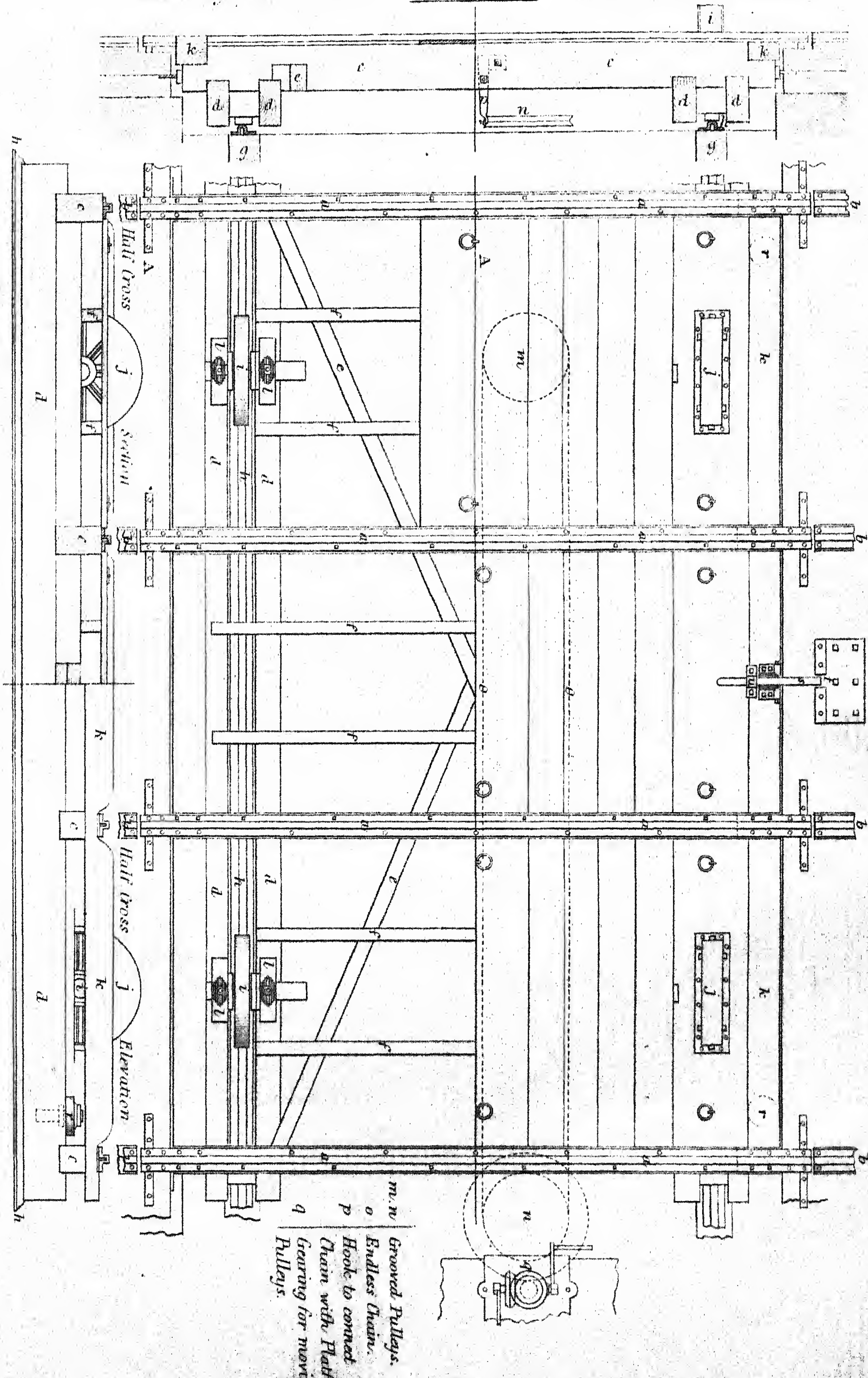
J. W. Lowry Sc.

London: Lockwood & C°. 7 Stationers' Hall Court, Ludgate Hill; 1860.

DRAWING OF PLATFORM.

Used occasionally instead of Turntable to transfer a Carriage from one Line of Rails to another.

Half Longitudinal Section. — *Half Longitudinal Elevation.*



J.W.Lowry, fc.

London; Lockwood & Co.
7 Stationers Hall Court, Ludgate Hill, 1860.

GOODS STATION.

Fig. 1.

Elevation on D.C.

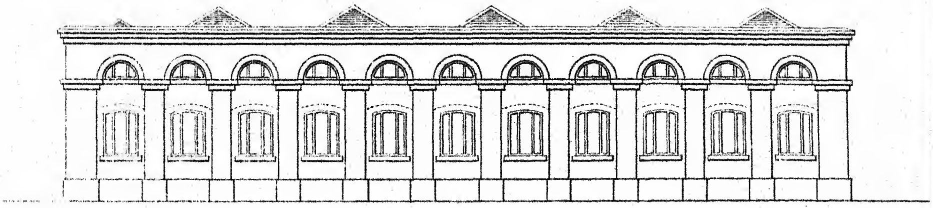


Fig. 2.

Elevation on A.B.

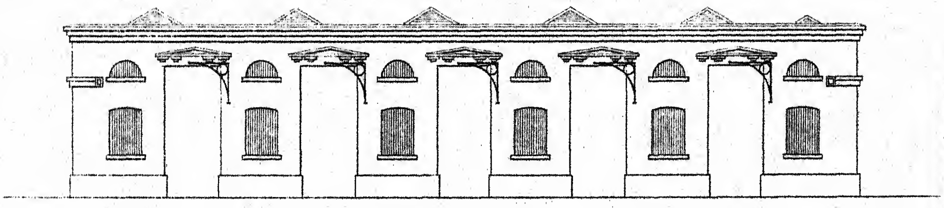


Fig. 3.

Ground Plan.

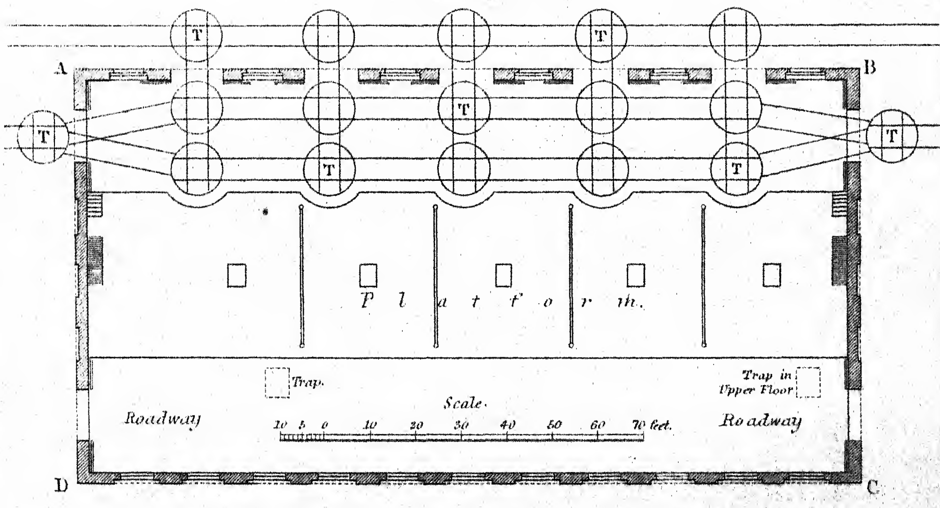


Fig. 4.

Tranverse Section.

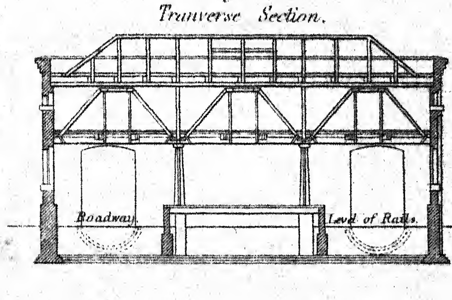
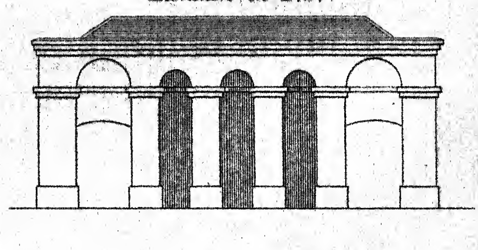


Fig. 5.

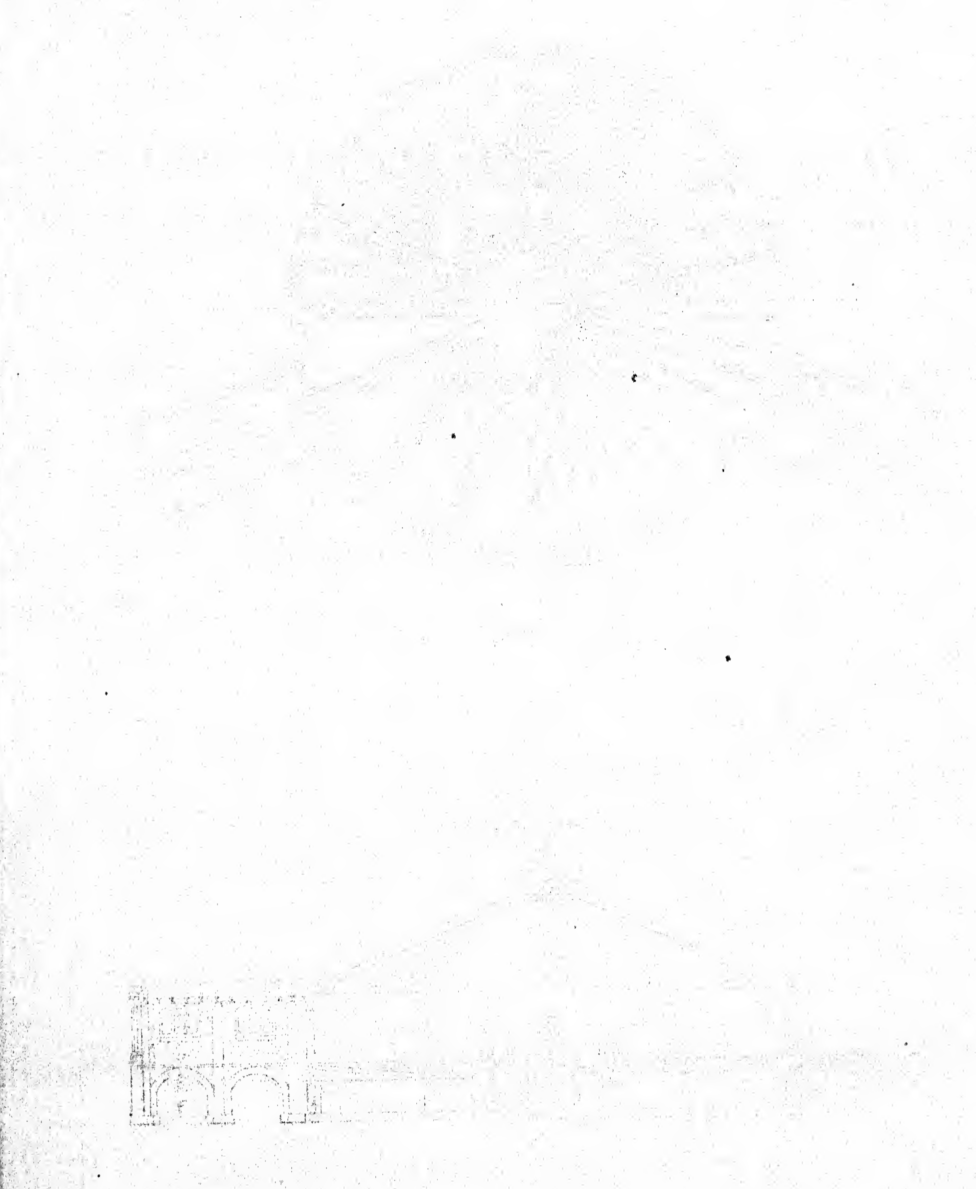
Elevation on B.C.



(T.T. *Turntables*)

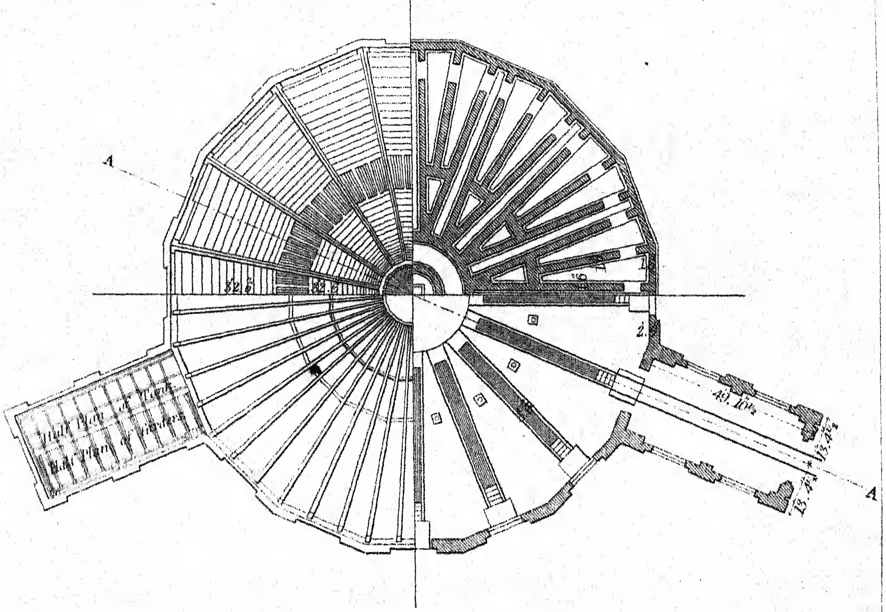
J.W. Lowry fc.

London: Lockwood & Co. 7 Stationers' Hall Court, Ludgate Hill, 1860.

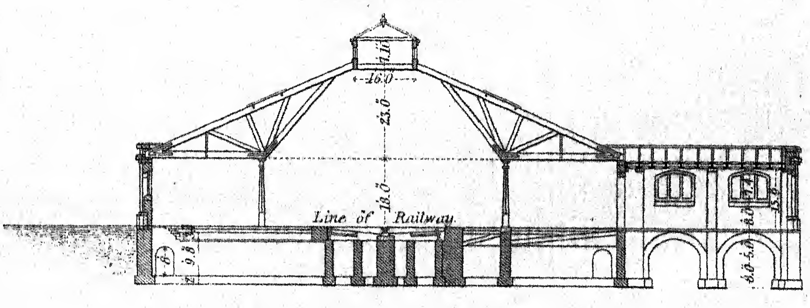


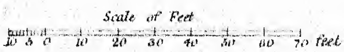
ENGINE HOUSE.

Plan.



Section at AA.





J.W. Lowry fc.

London: Lockwood & C°. 7 Stationers' Hall Court, Ludgate Hill: 1860.

STATIONS.

Fig. 2.

Elevation.

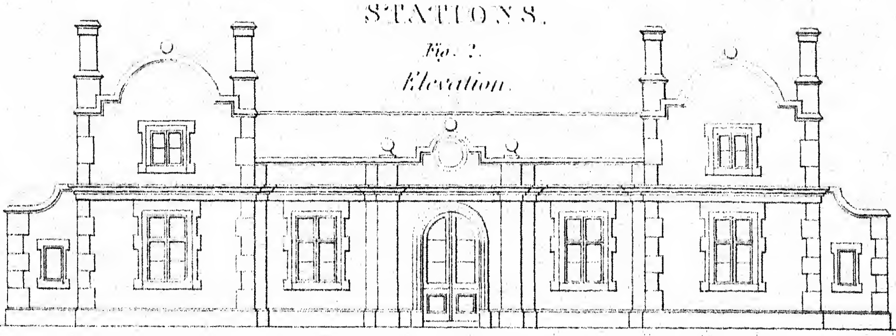


Fig. 3.

Ground Plan.

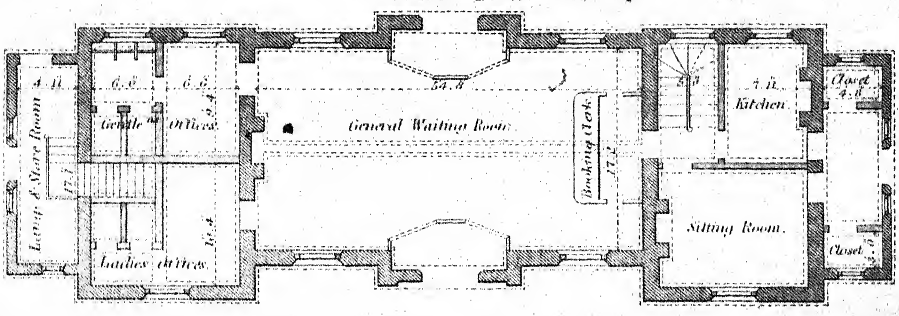


Fig. 4.

Section.

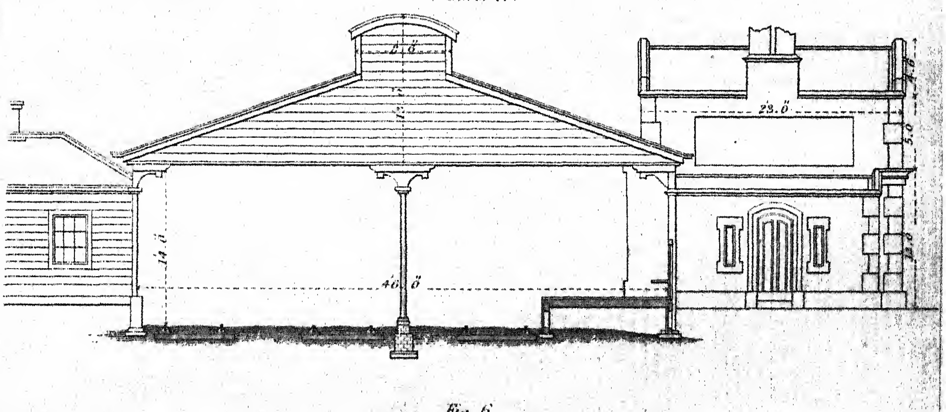
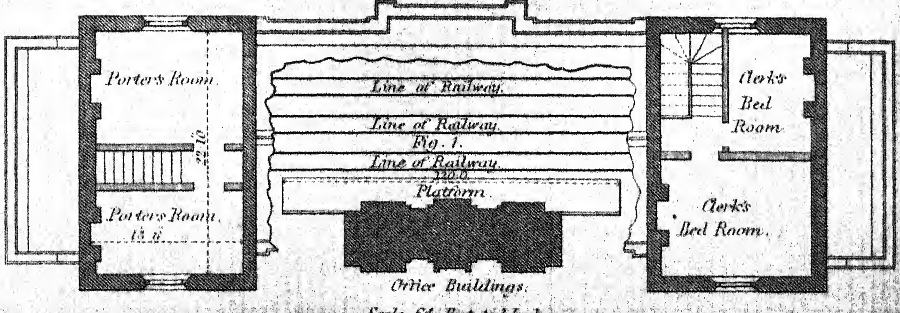


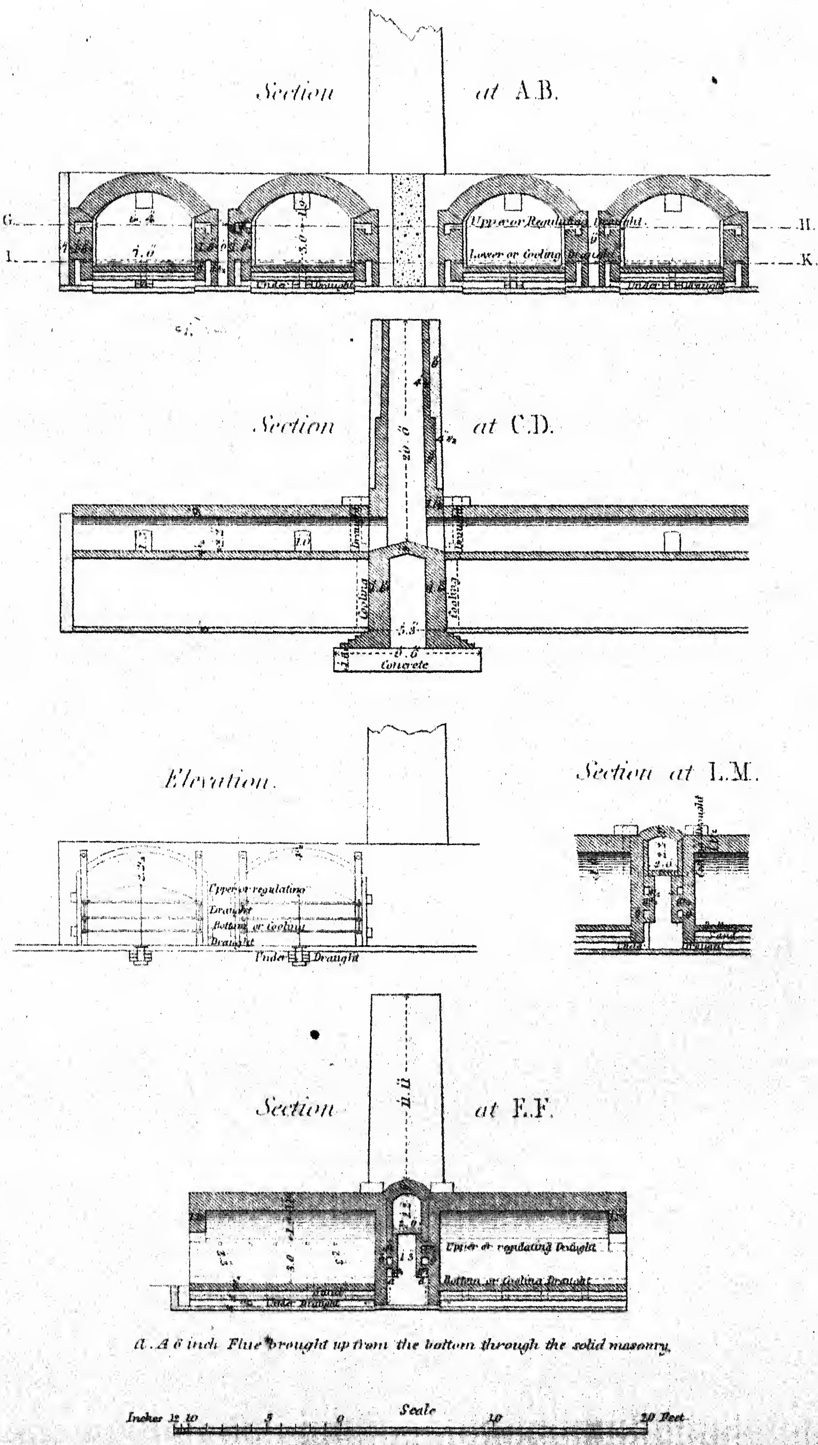
Fig. 6.



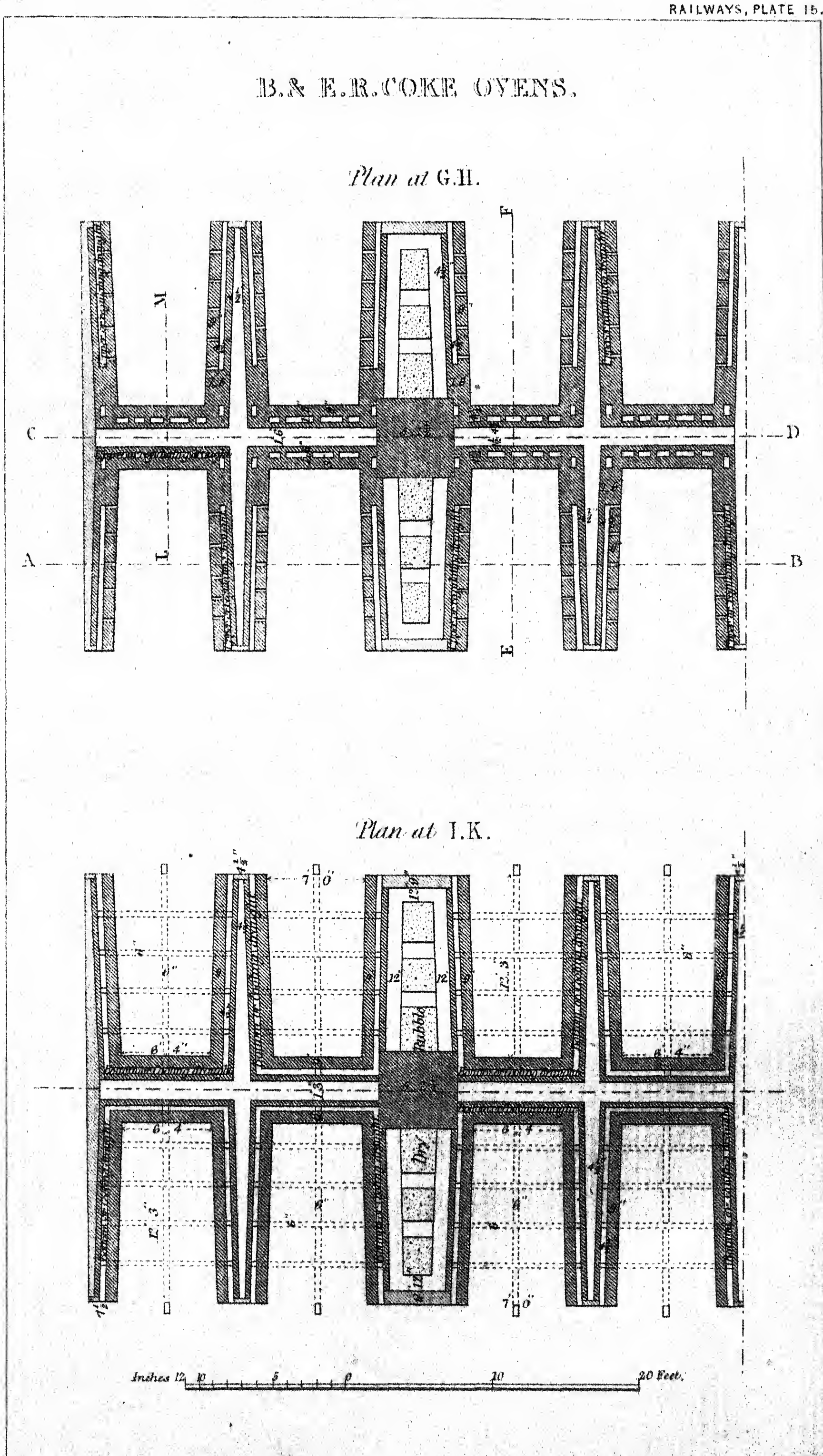
J.W. Lowry, fc.

London: Lockwood & Co. 7 Stationers' Hall Court, Ludgate Hill, 1860.

B. & E. R. COKE OVENS.

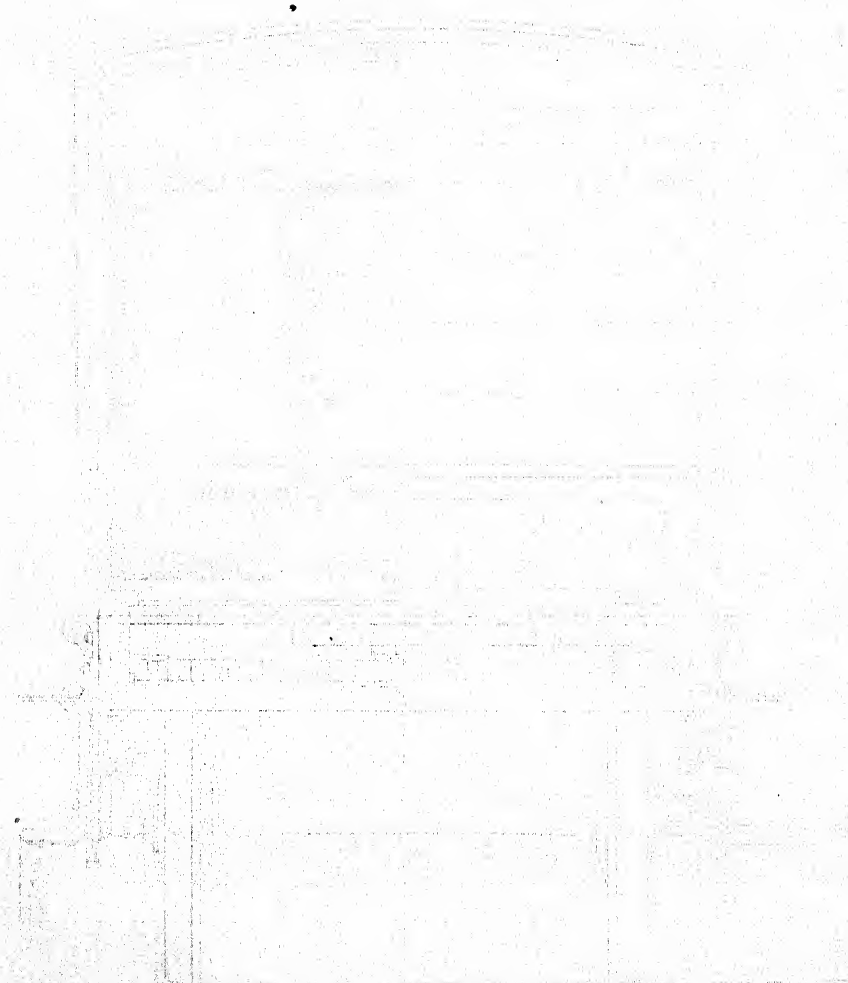


J.W. Lowry, fc.



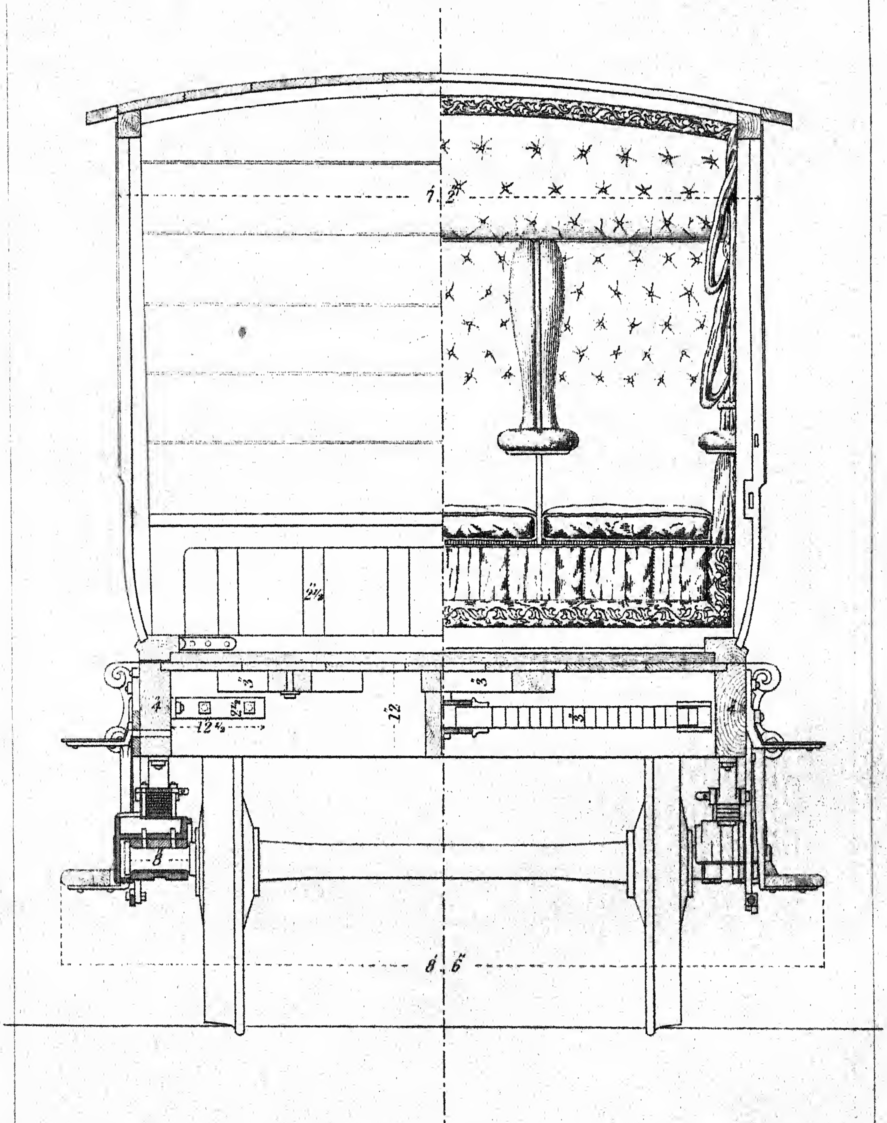
J. W. Lowry, fc.

London, Lockwood & C°. 7, Stationers' Hall Court, Ludgate Hill, 1860.



FIRST CLASS COMPOSITE CARRIAGE.

Half Transverse Sections.

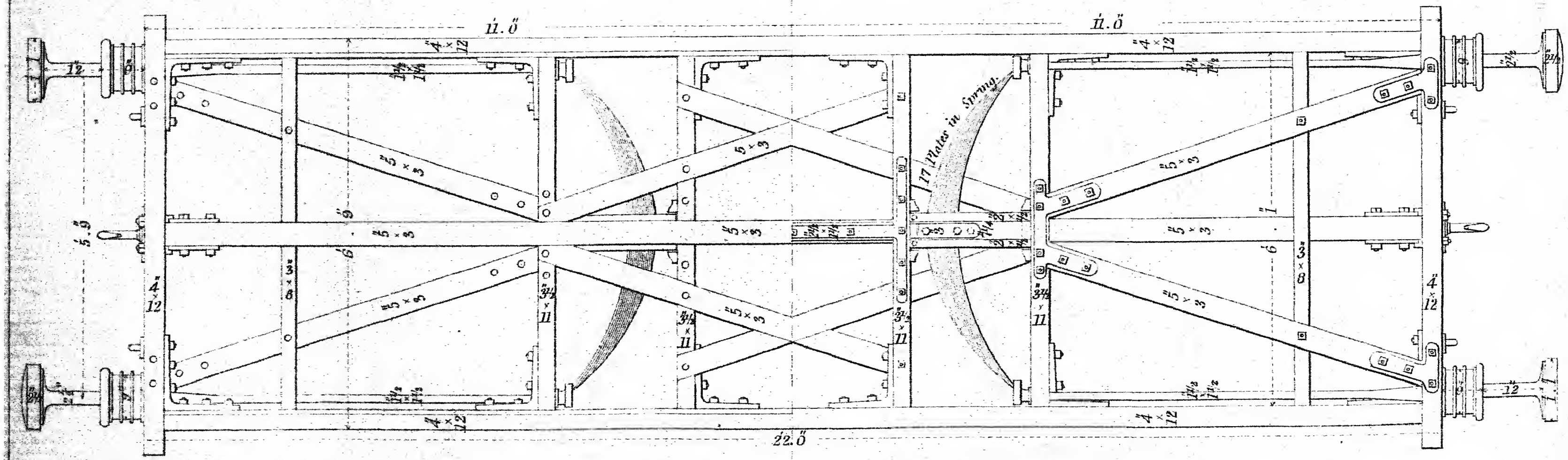


J.W. Lowry, fc.

London, Lockwood & Co. 7 Stationers' Hall Court, Ludgate Hill. 1860.

FIRST CLASS COMPOSITE CARRIAGE.

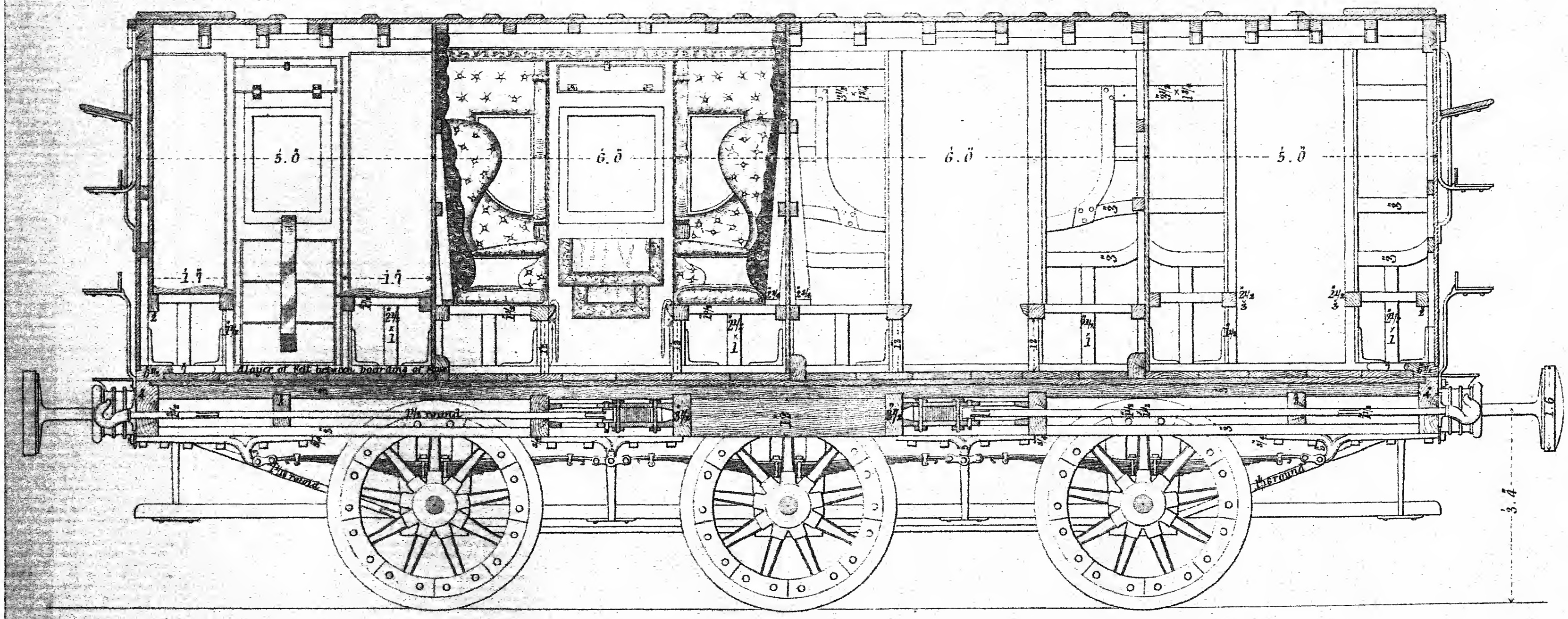
Half Plan of Framing. *Half Plan of Framing Inverted.*



London: Lockwood & Co. 7 Stationers' Hall Court, Ludgate Hill: 1860.

FIRST CLASS COMPOSITE CARRIAGE.

Half Longitudinal Sections.

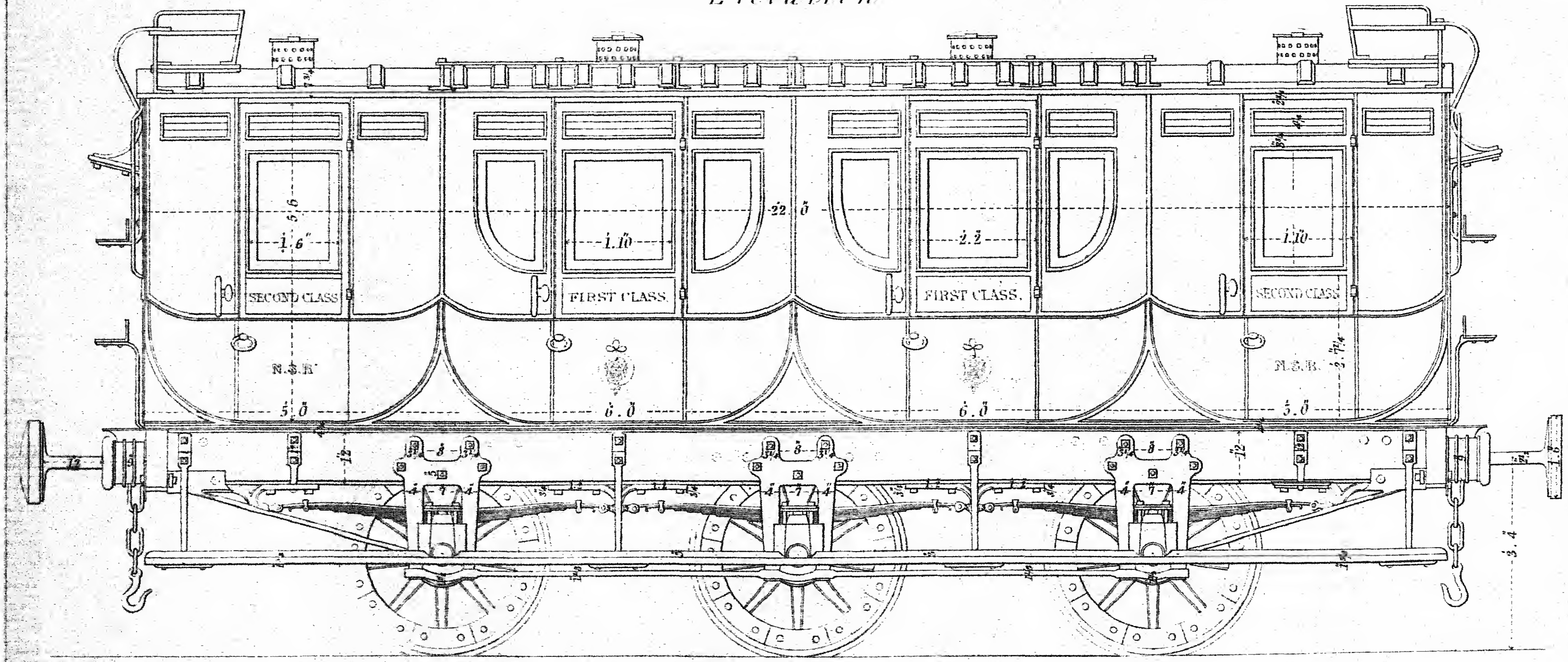


J.W. Lowry sc.

London: Lockwood & Co. 7 Stationers' Hall Court Ludgate Hill: 1860.

FIRST CLASS COMPOSITE CARRIAGE.

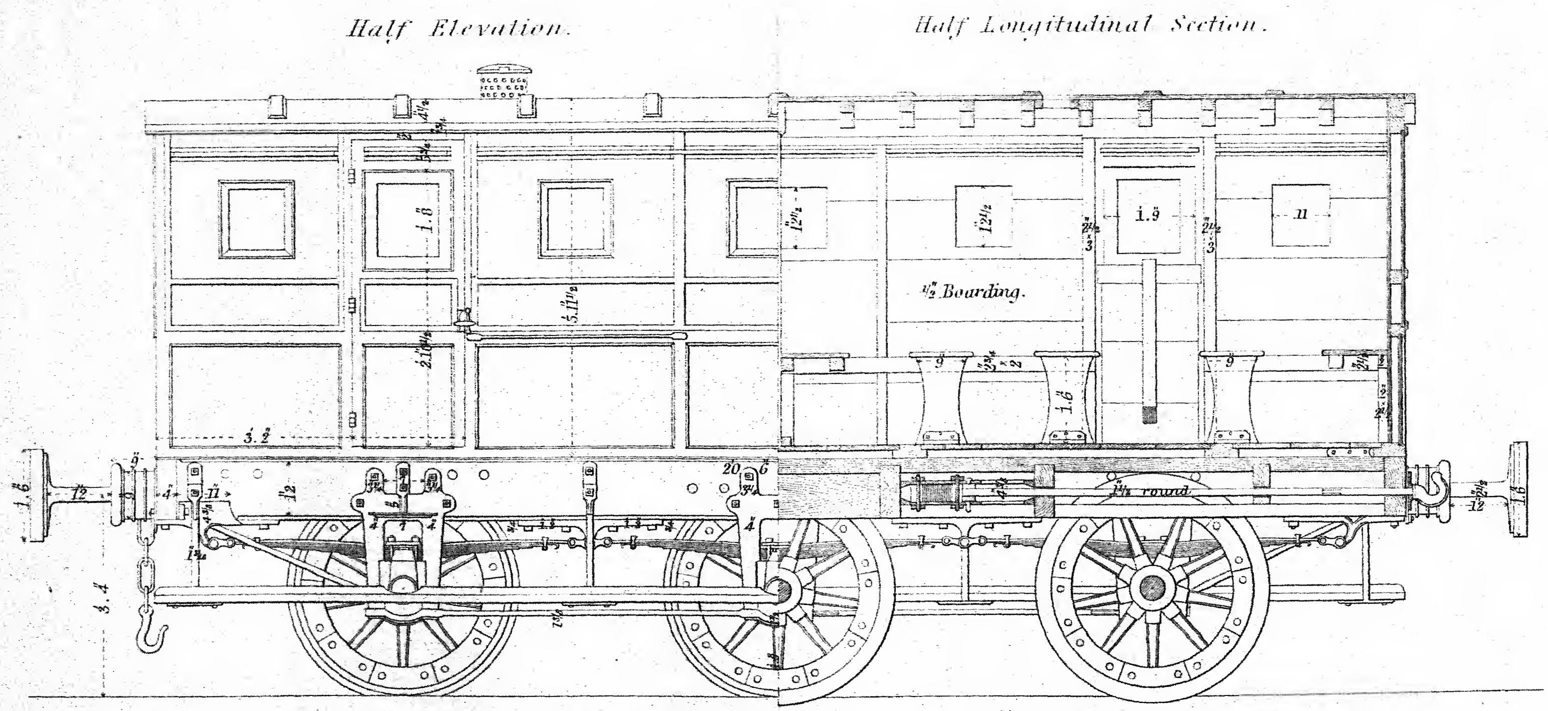
Elevation



J. W. Lowry, fc.

London: Lockwood & Co. 7 Stationers' Hall Court, Ludgate Hill; 1860.

THIRD CLASS CARRIAGE.

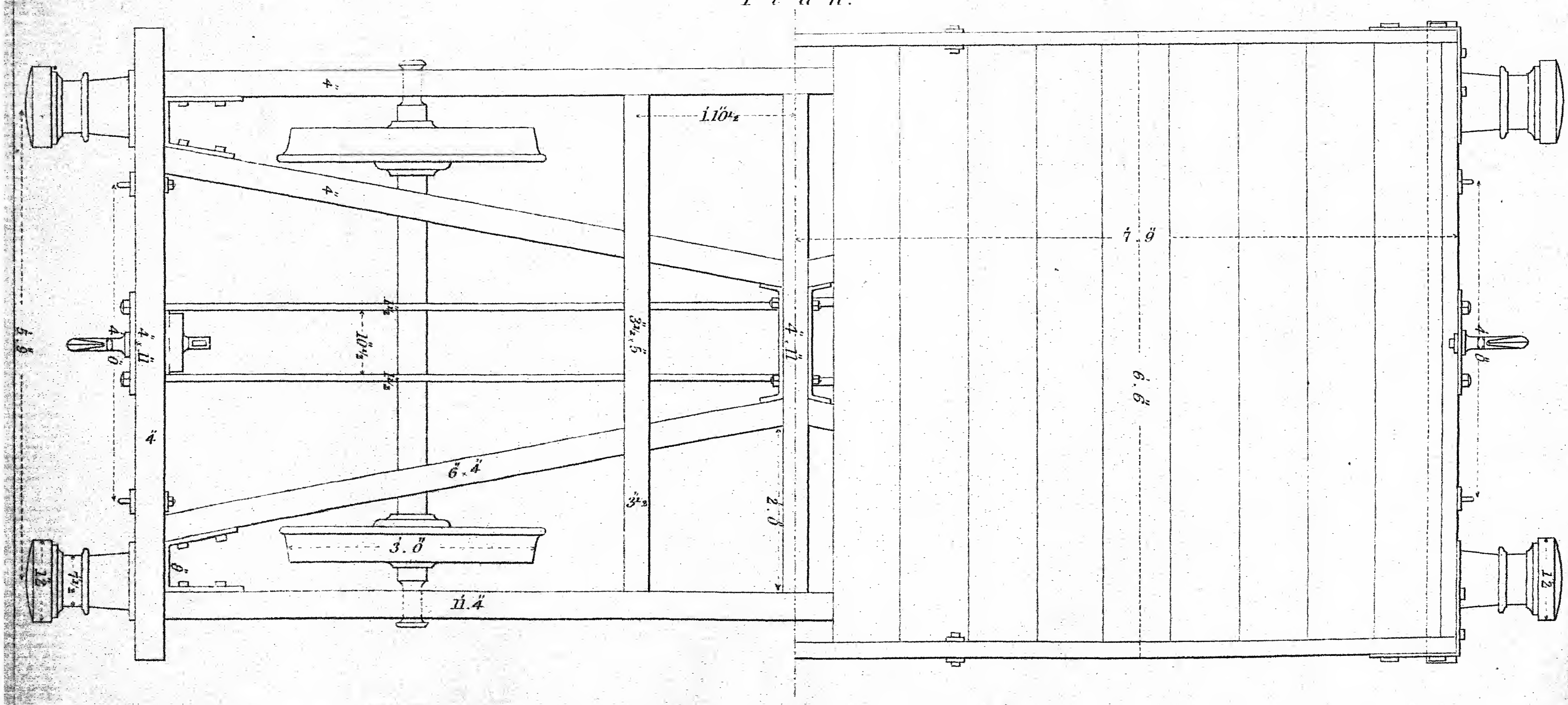


J.W.Lowry, fc.

London: Lockwood & Co. 7 Stationers' Hall Court, Ludgate Hill: 1860.

FRAMING OF LOW SIDED GOODS WAGON WITHOUT SPRING BUFFER.

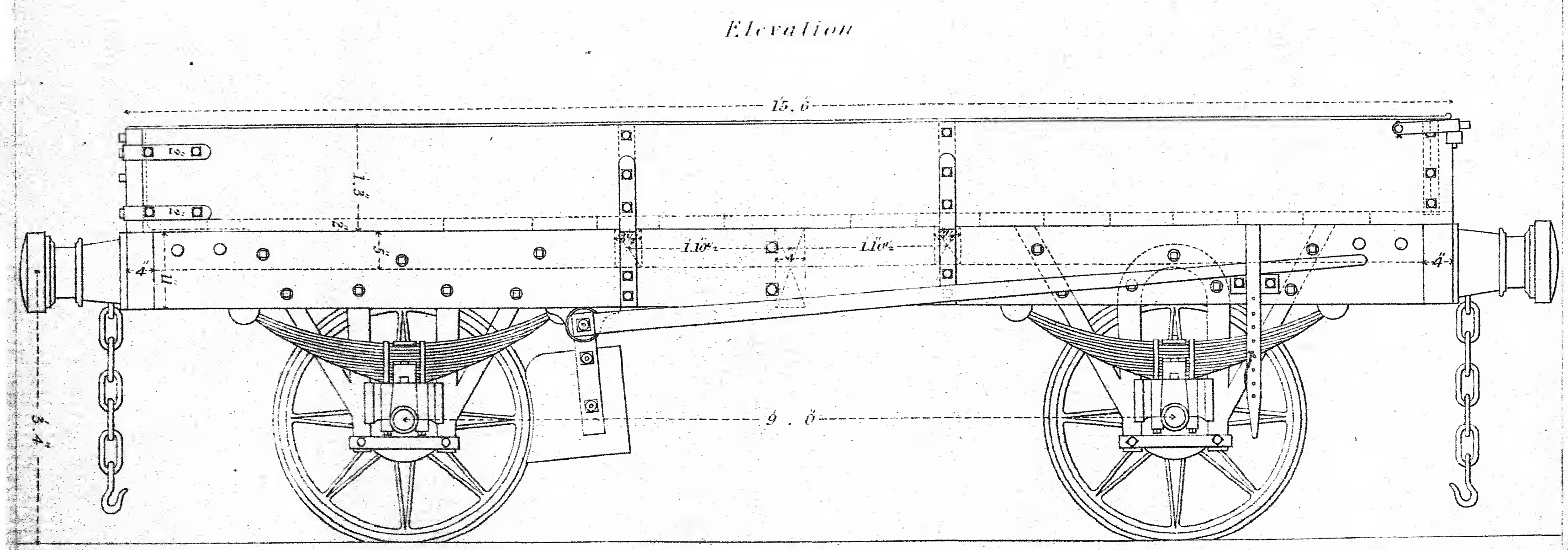
Plan.



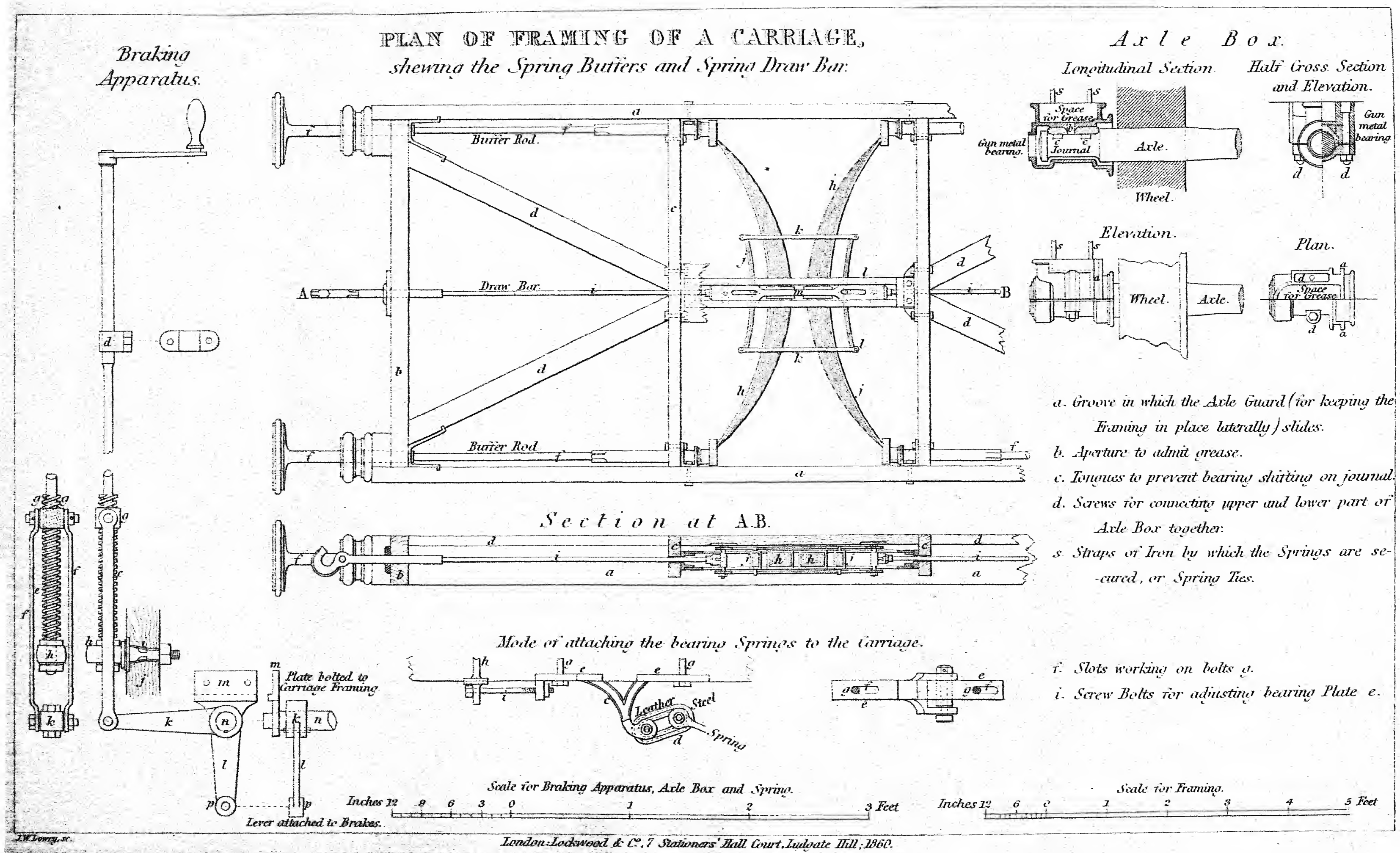
J.W. Lowry, sc.

London. Lockwood & C°. 7 Stationers Hall Court, Ludgate Hill. 1860.

LOW SIDED GOODS WAGON WITHOUT SPRING BUFFER.

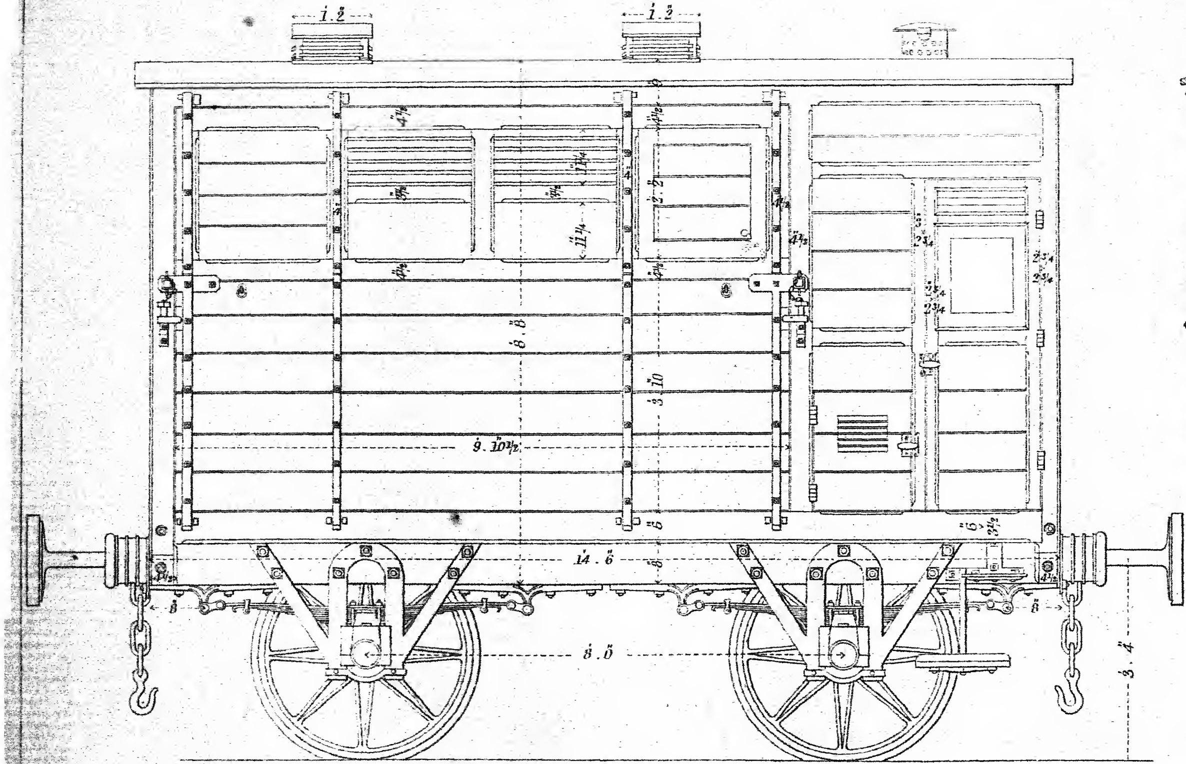


London: Lockwood & Co. 7 Stationers' Hall Court, Ludgate Hill: 1860.
J.W.Lowry fc.

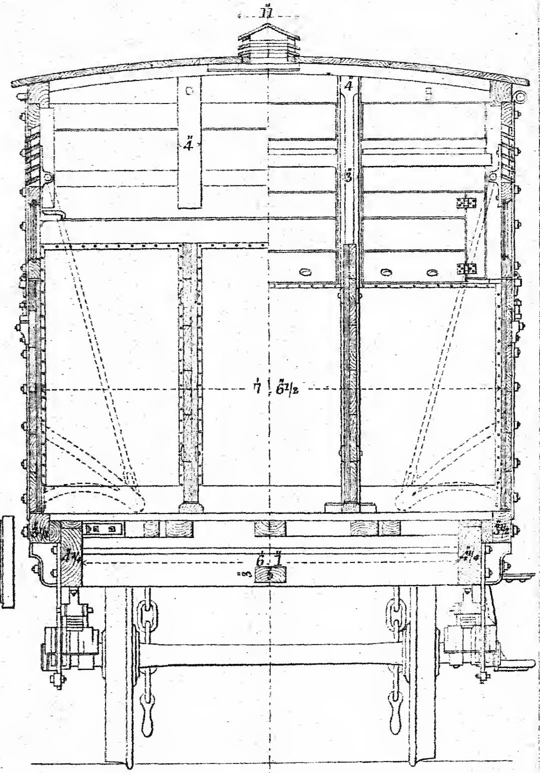

PLAN OF FRAMING OF A CARRIAGE,
shewing the Spring Buffers and Spring Draw Bar.
Braking Apparatus.
Buffer Rod.
Draw Bar.
Buffer Rod.
Section at A.B.
Mode of attaching the bearing Springs to the Carriage.
Leather
Steel
Spring
Plate bolted to Carriage Framing.
Lever attached to Brakes.
Axle Box.
Longitudinal Section.
Half Cross Section and Elevation.
Space for Grease
Journal
Gun metal bearing.
Axle.
Wheel.
Gun metal bearing
Elevation.
Plan.
Wheel.
Axle.
Space for Grease
a. Groove in which the Axle Guard (for keeping the Framing in place laterally) slides.
b. Aperture to admit grease.
c. Tongues to prevent bearing shifting on journal.
d. Screws for connecting upper and lower part of Axle Box together.
s. Straps of Iron by which the Springs are secured, or Spring Ties.
f. Slots working on bolts g.
i. Screw Bolts for adjusting bearing Plate e.
Scale for Braking Apparatus, Axle Box and Spring.
Inches 12 9 6 3 0 1 2 3 Feet
Scale for Framing.
Inches 12 6 0 1 2 3 4 5 Feet
J.W.Lowry, sc.
London: Lockwood & C°. 7 Stationers' Hall Court, Ludgate Hill; 1860.

HORSE BOX.

Elevation.



Transverse Sections through C on Plan.



J.W. Lowry, fc.

London: Lockwood & Co. 7 Stationers' Hall Court, Ludgate Hill: 1860.

WATERING APPARATUS

Fig. 1.

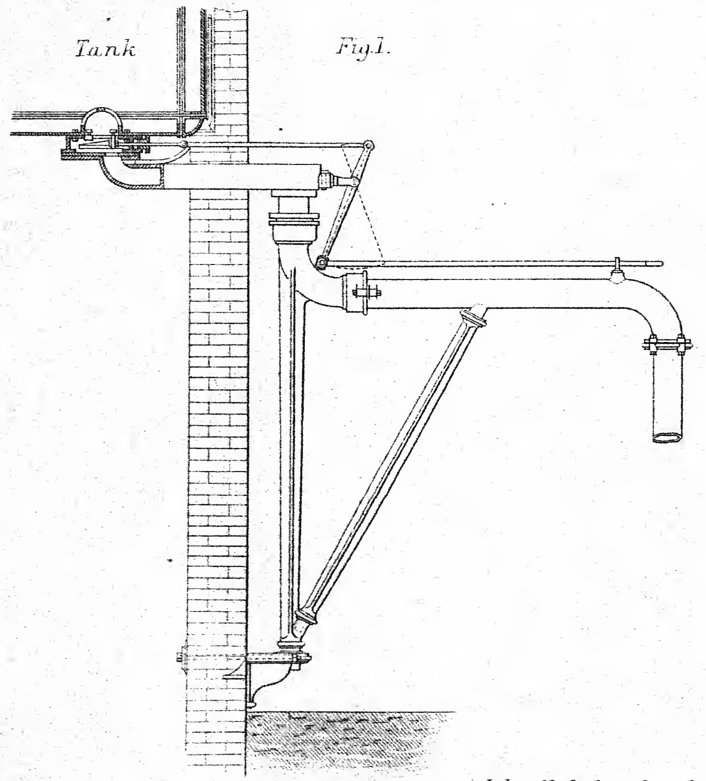
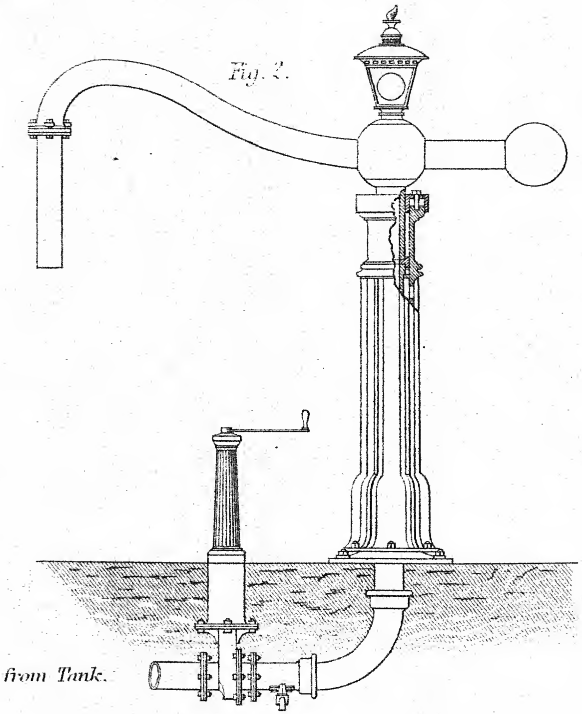


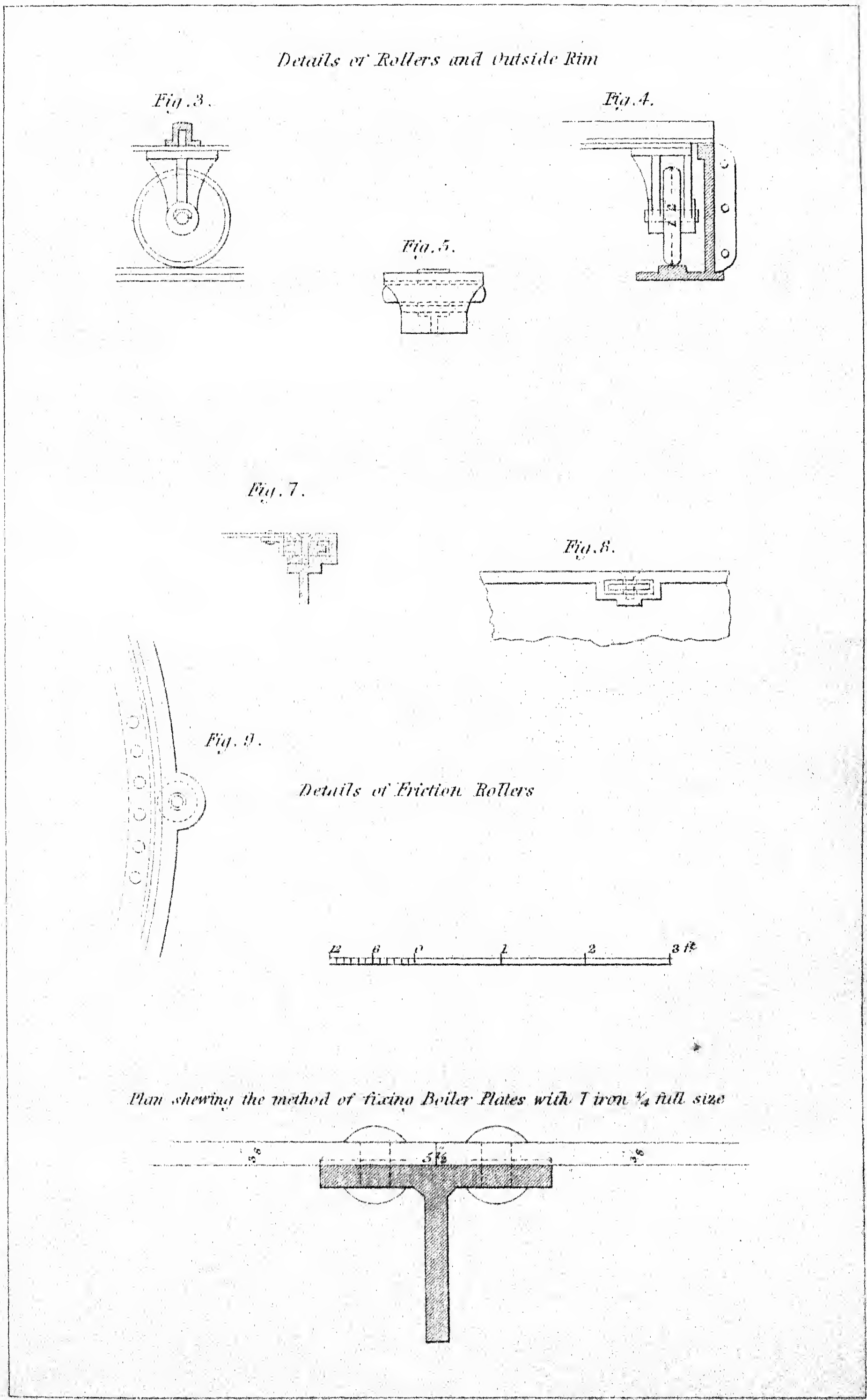
Fig. 2.



Inches 12 6 0 1 2 3 4 5 6 7 feet.

J.W. Lowry, fc.

London: Lockwood & Co. 7 Stationers' Hall Court, Ludgate Hill; 1860.



J. W. Lowry fc.

London: Lockwood & Co. 7 Stationers' Hall Court, Ludgate Hill, 1860.

Fig. 1.

Plan of wrought Iron Turntable 15 feet diameter

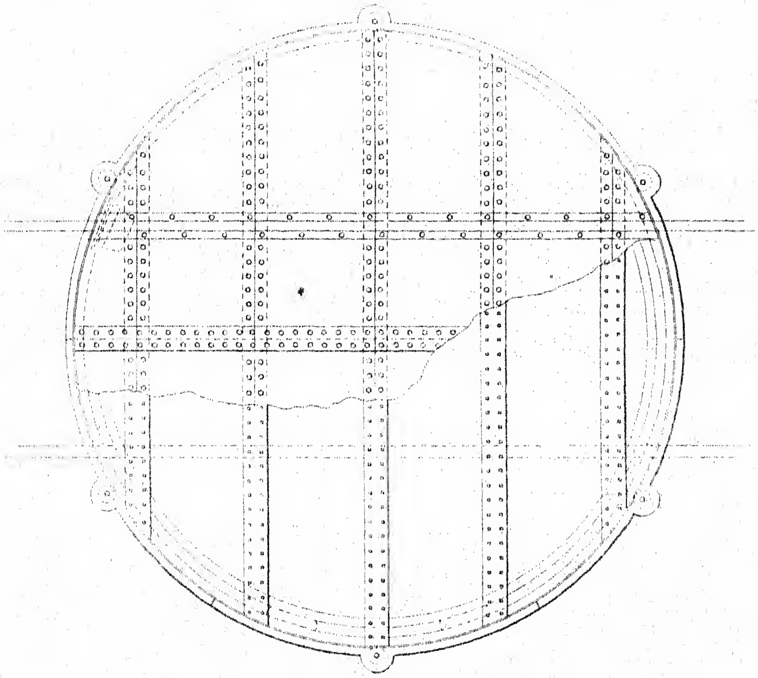
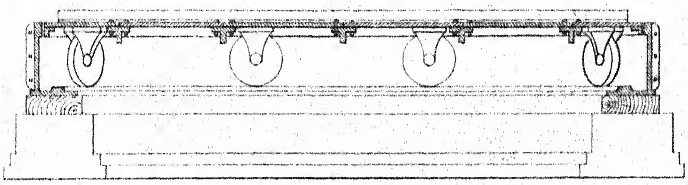


Fig. 2.

Crofs Section



12 6 0 1 2 3 4 5 6 7 8 ft

J. W. Lowry fc.

London: Lockwood & Co. 7 Stationers' Hall Court, Ludgate Hill, 1860.

EARTHWORKS

Excavating

Fig. 1.
Longitudinal Section of Fig. 2.

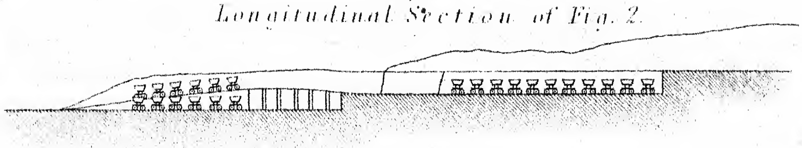
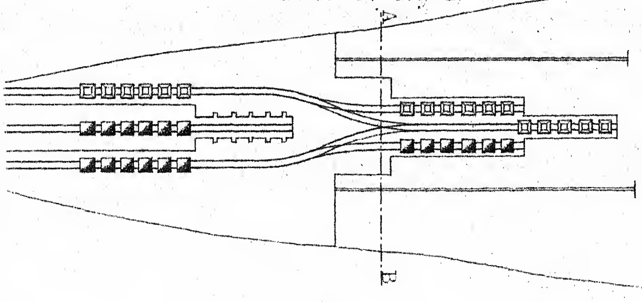


Fig. 2.
Plan of Fig. 1.



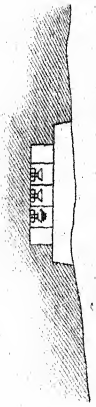


Fig. 3.
Section on AB of Fig. 2.

EARTHWORKS

Embankment

Fig. 1.
Section of Fig. 2.

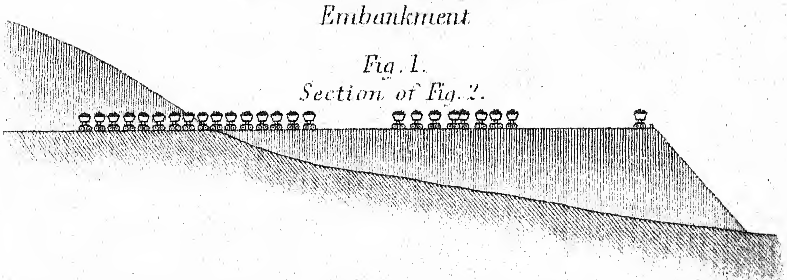
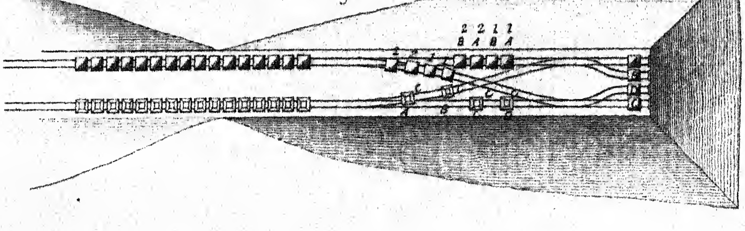


Fig. 2.
Plan of Fig. 1



J. W. Lowry, sc.

London: Lockwood & Co. 7 Stationers Hall Court, Ludgate Hill. 1860.

going out of the road for a short distance, as also whether any great improvement could be made in the general direction of any part of the road by adopting a new line altogether for a considerable distance; and what amount of work is necessary in either of these cases.

"Particular attention should be paid to the ascents and descents upon the road; whether they are gradual and easy, or abrupt, rugged or stony, having short turns or other difficulties; whether the road is wide enough in those parts which run along the sides of hills, and whether it is even or canted off the level, so as to be unfavourable for carriages.

"In those parts where the road passes between walls, or where it forms a hollow way between banks of earth, rocks, or other obstacles, its breadth ought to be measured; and it should be stated also whether it can be widened, or the obstacles which confine it removed.

"The ferries, bridges, fords, &c. met with on the road should be particularly attended to; the possibility of obstructing or breaking up the road, so as to prevent its being used by the enemy, or of destroying the bridges and fords upon it, should be stated: the means of effecting these objects should be pointed out, as also the labour and time requisite for such works.*

"The distances of the places along the road should be given, both in the measures of the country and in English miles, averaged as accurately as possible: the time required to travel the different distances at the ordinary walk of a man or of a horse should be also stated. The places to the right and left near the road should be mentioned, their distances from the road, and at what points the communications to them strike off from it.†

"Care must be taken that the names of towns, villages, rivers, &c. are spelt in the same manner as by the natives of the country; and when the spelling and pronunciation differ very much, the names should be written (in a parenthesis) as they are pronounced.

"5th. *Camps and Positions.*—All strong passes, posts, or more extensive positions which present themselves either upon the line of a road or in any other situation, as also all places favourable for encamping or bivouacking troops, either with a view to remaining there, or with reference merely to convenience on a march, should be particularly described; their situation, extent, facility of access, nature of soil, supply of water at all seasons, quantity and kind of wood, and whether in sufficient abundance for hutting the troops, or only for furnishing fuel.‡

"A sketch of the ground, upon a pretty large scale, should always accompany the Reports; those of positions should never be made upon a smaller scale than 4 inches to an English mile; general sketches may be made upon a scale of 2 inches to a mile, and tracings of roads upon a scale of 1 inch to a mile.

"The Officers of the Department ought to avail themselves of every opportunity that offers to verify and extend their information upon the points above mentioned; and the information obtained should be always put into such a shape that it may be transmitted to the head of the Department, or be applicable to the use of the General Officer under whom they are immediately employed.

"In all Reports they will be pleased to state distinctly what parts of the information which they contain rest upon their own personal examination of the objects in question, and what upon the authority of others; and in the latter case, they will

* *Vide* articles on "Bridges" and "Demolition." † *Vide* annexed form.
‡ *Vide* article "Castrametation."

mention the source of their information, in order that a judgment may be formed of the degree of credit to which they are entitled.

"They will consider it their duty to apprise the Quarter-Master-General of every reconnaissance, report, sketch, &c., executed by them; whether done by order of the General Officer to whom they are attached, or upon any other occasion, as all their labours are understood to belong to the Department, and to be the property of the public.

(Signed) "GEO. MURRAY, Q.M.G.

"Cartaxo, Dec. 2nd, 1810."

In addition to the points mentioned in the above instructions, the Report should contain information as to the means of supplying troops with provisions, viz. cattle, stores of corn, &c., also as to bakeries, and buildings adapted for barracks and for hospitals; and it should describe the facilities for concentrating troops on particular points by means of the roads shewn on the plan; it should also state to what extent the banks of the rivers are liable to be flooded by falls of rain, melting of snow, or breaking of embankments, and how long it usually takes for these inundations to subside; the alterations liable to be caused by floods in the direction or depths of the channels, and the periods during which the rivers are usually frozen over; what materials are available for making rafts, such as are afforded by timber-yards, the beams of houses, trees, &c.; what number of boats can be collected at given points within a certain time, the nature and sizes of the boats, and the number of men who can be obtained to manage them; the exact width of the bridges, the number and spans of the arches, the nature of their masonry or other materials, the facilities for fording the river near them, so as to prevent a column in passing over on the line of march being lengthened out by the narrowness of the roadway; the space available for deploying on each side, or for constructing works, as bridge-heads; the probabilities of certain parts of the roads being rendered impassable by the march of troops over them, and the means at hand for repairing them with fascines, rails of fences, &c.; also whether, in that case, carriages could be taken through by merely sending Infantry to assist.*

Although railways are likely to be rendered useless for a time by the enemy, complete information with regard to them must be obtained, viz. whether they have single or double lines of rails, the positions of the viaducts, junctions, stations, &c., and the facilities for repairing parts broken up.

The Officers making a reconnaissance must take care to verify *personally* as much as possible of the information which they may obtain; but all persons who may be met with should be cautiously and separately interrogated, employing art rather than force,—inquiring about subjects of a different nature from that on which information is required, so as to lead to it *casually*, and writing down what is important without being observed, so as to prevent being suspected by the enemy, who, by sending out a few parties, would probably surprise them; to prevent which, the greatest precautions must be taken, particularly by keeping the horses ready saddled at night. Prisoners or deserters should be interrogated as to the numbers, strength, and position of their regiments and divisions, the names of the Generals, the positions of detachments and of head-quarters, alterations of positions expected, latest orders given out, numbers of wounded or recruits, quantity and localities of provisions,

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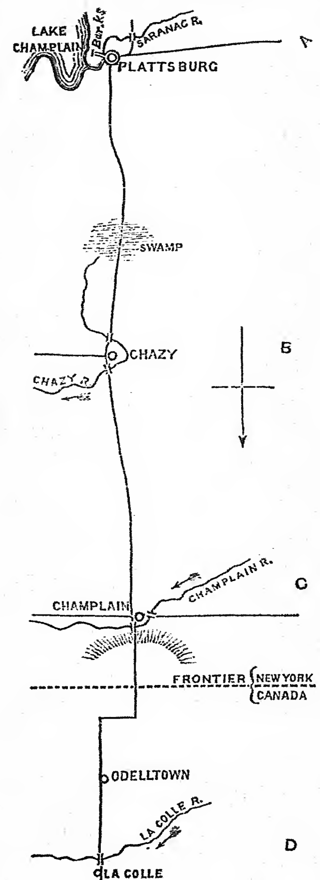
* See "Passage of Rivers."

Distance.		Places on the Road, with Description.	Accommodation.				Distance to Places near the Road.	Sketch of the Road.	Distance to Places near the Road.	Difficulties on the Road, proportions of swamp and forest, description of houses, soil, fences, water, &c.	Positions to cover a retreat either way; bridges, ferries, fords, boats, &c.
Total.	Inter.		No. of Houses.	Men, temporary.	Men, permanent.	Horses, permanent.					
miles.		Plattsburg—a shallow harbour at the mouth of the Saranac, protected by a wooden breakwater: on the south side are barracks of wood; a few houses of brick in the town; the rest are of wood framed.	250	3000	1500	500			Malone, 50	From A to B—Country level and well cleared except at the swamp 9 miles from Plattsburg, — where there is a tangled cedar forest for half a mile.	
	12	Chazy contains a large stone mill commanding the southern bridge; the rest of the houses are wooden.	60	500	200	30	Chazy Landing Place, 3			From A to D—Road good in dry weather, but clayey and tenacious after wet; the fences all wooden.	At Chazy is a good position facing either way, and another on the north side of Champlain, facing the south. The rivers are all fordable, and bridges all of wood.
22	10	Champlain lies in a hollow, quite commanded, and contains large stores and mills, mostly wooden.	100	1000	400	50	Caribou, 2½		Perrysville, 7	From B to D—Country undulating and cleared along the road; but there are broad belts of forest, in all directions, within half a mile of it.	
26	4	Odelltown — a scattered village.	30	200	100	10				The houses are all of wood, framed.	
29	3	La Colle, hamlet, with a good inn.	20	200	100	20	*		*	There is good water in wells and streams everywhere.	



N.B.—This folds conveniently into three parts at the points *.

artillery, siege, and bridge equipments; also whether the enemy are repairing any roads, bridges, &c., or constructing intrenchments; and inquiries must be made of the principal inhabitants as to the movements and positions of the enemy, as also the arrangement of their columns on the line of march.

Spies must be employed with great caution, making use of them so as to be checks upon each other, and giving them nothing in writing but what will serve to mislead the enemy; also paying them liberally, and, if possible, retaining their families as pledges for their fidelity.

The subject of reconnoitring is entered into much more fully than can be done in a work of this nature, in "Chatelain's Traité des Reconnaissances Militaires," published in 1847-50, which may therefore be consulted with advantage.

The form given on the next page for Reports on particular roads has been found very useful, as it shows at a glance the information required, which must often, however, be much more detailed than that here given: the approximate heights of the prominent points traversed by each should be marked upon the sketch: the difference of level required to obtain these may be roughly estimated by noting the points where the horizon, if it were that of a plain or of the sea, would cut the sides of the hills, which may be considered to be on nearly the same level as the spot where the observer stands, from whence, by remarking the apparent heights of men, houses, or trees near them, the difference of level between them and other points may be judged of.

A reconnaissance by a body of troops, to discover an enemy's force and position, must be planned in accordance with the nature of the country, and its strength must depend very much upon the chances of being surprised; men should be detached to every commanding height near the road, to observe the movements of the enemy, and telegraph accordingly to the main column; the Officer commanding must also arrange his plans to secure a retreat, by remarking the points favourable for delaying an assailant, or likely to cover an ambuscade.

A sketch must be made showing all the features of the country traversed, the positions of the enemy, the nature of the approaches leading to them, and of the obstacles protecting them, as well as the situation of field-works, artillery, and cavalry. Sometimes an attack made with much noise on one side of a position may draw off the enemy's attention from that where the reconnaissance is being made, and individuals may often creep close up to it under cover of hedges, &c., so as to insure a more satisfactory examination of the defences; but care must be taken not to compromise the retreat, and not to halt, except in open spots the approaches to which can be seen for some distance; and it must be recollected that it is of great importance not to attract too much attention to the real object of the reconnaissance.

From the dust raised and the space occupied by the enemy's troops on the march, and from the number of their fires (calculating on about six men to each of the latter), their strength may be estimated; it may be remarked also that if the glitter of their arms is brilliant, they are probably advancing, and if not, retreating.

The extent of cover from the enemy's fire afforded by hollow ground, &c. in front of his position must be carefully noted; likewise whatever can be discovered relative to the country beyond the enemy's position and on its flanks, as well as the movements taking place among the enemy's troops and carriages.

Reconnaissance of a Fortress preparatory to an Attack. Having procured the best plan of it which can be obtained, and such information as the people living near it can furnish, an Officer must approach by daylight, with but few attendants, yet supported by small guards concealed in their rear, to verify and correct the plan and

ascertain the best direction in which to advance for the purpose of examining the details more closely, which he will do afterwards at night with a strong guard; and by retiring gradually as day dawns, will be able to see most at that time without being discovered or interrupted. Balloons, anchored or free, may also perhaps be used in calm weather for this purpose sometimes.

The points most necessary to remark are the hollows and fences affording cover; the roads by which the guns and stores can be conveyed to the projected batteries without being exposed to the fire from the fortress; the material, height, and slope of the glacis, and the features of the country around; the depth of the ditches and of the water in them; the condition of the flanking defences; also the nature and position of the bâtardeaux, and state of the revetments, parapets, hedges, and other obstacles, &c., &c.

By the sound of tools, the appearance of scaffolding, &c., or by information received from the workmen, may be discovered at what parts repairs are going on or have been lately executed, as also what mine-galleries, retrenchments, &c. have been constructed; and the lightning-conductors will often point out the situation of the magazines.

Three ladders braced together, or a more permanent stage, may be employed sometimes advantageously for watching the operations of the besieged.

After it is decided on which side to attack, further details of the plan of the works may be obtained by taking the prolongations of the parapets when the shadows mark them most distinctly, and thus a more accurate plan for the Attack may be constructed, on which the projected approaches can be laid down.

REPORTS, MILITARY.—The Editors were requested to insert an article on the subject of framing Military Reports, to assist the memory of an Officer upon any emergency in the field; and in accordance with this wish the following suggestions were offered by the late General Lewis:—

1. It has been found convenient, and was directed by an order of the Master-General and Board of Ordnance, that all Reports should be written half-margin on foolscap paper, and each paragraph numbered: this arrangement enables the superior Officer to whom the Report is addressed to make marginal notes, and the numbering of the paragraphs affords an easy reference to the several parts of the subject.

2. All Reports should be accompanied by drawings, either as sketches of the ground, or views of the principal features; and the more they are illustrated by vignettes and diagrams, which may be given on the margin or in the paragraphs of the Reports, the more interest will be given to them, as facilitating a quick comprehension of the subject.

3. Many parts of a Report may be given in a tabular form, which should be done when possible.

4. An early attention to the object of the Report, and the instructions or orders received for making it, will save much trouble: it is also necessary to arrange the subjects in the order of their relative importance, so time may not be lost in seeking for information of little value.

5. An important consideration is the condensation of facts in the smallest possible space, in logical order, so as to keep up the interest of the subject,—and by inserting unimportant details only in notes or in an Appendix to the Report. Care should be taken that little extraneous matter is given; and if any thing foreign to the purpose of

the Report should be considered useful, it may be placed also in the Appendix, with an allusion to it in the body of the Report.

6. The purport or substance of each paragraph of the Report should be briefly inserted in the blank half-margin side of the paper; this enables the reader to recur to any part without trouble.

7. Military Reporters should be careful in recording hearsay statements, and offering opinions on surmise; and if vague, the authorities should be quoted, and the value of the evidence stated: facts are what is required, based upon ocular demonstration.

8. In framing a Report, much valuable information will be found in this work, under the heads of 'Field Sketching,' 'Geology,' and 'Reconnoitring.' In this last the several subjects necessary to notice are given, and the most important points of each are inserted in detail. The articles on the 'Passage of Rivers,' the 'Construction of Roads,' and 'River Navigation,' also 'Statistics,' will afford valuable information to the Reporter, according to the tenor of his instructions.

9. The application of ground to military operations, whether offensive or defensive, for strategical or tactical purposes, may be considered the most difficult of tasks to a Military Reporter, and few opinions should be given, except those formed from incontrovertible facts; and assertions that a river is impassable, a country inaccessible, a place impregnable, and roads impassable, should only be offered on most accurate information; and if not from personal inspection, the authority must be given. To suggest that particular sites afford good positions for offensive or defensive tactical operations, or that they are well suited for intrenched camps, posts, or positions for strategical operations, should be given hypothetically, if not based upon a thorough acquaintance with the country, and some knowledge of the Art of War.

10. Finally, in arranging the Report, the classification of matter under different heads should be attended to, and subjects separated, keeping the descriptive, statistic, political, and military parts distinct, as well as other points unconnected with each other.—G. G. L.

RIVER AND INLAND NAVIGATION.*

SECTION I.—RIVERS.

General Remarks.

1. Rivers, as far as they are applicable to the purposes of internal navigation, may be regarded as natural canals, whose section, inclination, and speed, or rate of flow, vary within limits of considerable range; and the volume of water they carry, and the nature of its movement, are proportionately affected by such variations. Running waters are also utilized as motive powers, not only for the mills placed immediately upon them, but also for the descending navigation.

2. Those who may desire to study in detail the laws which connect the general phenomena of the elevations of the mountain ridges, and the direction of rivers, are referred to the works of Messrs. Lamblardie, Brisson, De Torcy, and Denaix. Sir C. Lyell's incomparable work, the 'Principles of Geology,' and the more modern treatises upon Physical Geography, contain much interesting information bearing upon this branch of practical science.

* By George R. Burnell, C. E.

3. For present purposes it will be sufficient to consider rivers as presenting, from their source to the places where they fall into other rivers or the sea, the following characters: In plan, they present a water section or line, which widens with more or less regularity. In longitudinal section, they present concave curves both at the bed-line and at the surface (with occasional exceptions): these curves are not always either concentric or parallel one with the other. The total length measured upon the axis of the longitudinal profile in all cases exceeds the length measured in a straight line between the two extremities.

4. When rivers fall into a sea subject to tidal influences, or into another river whose level is variable, their plans and profiles vary unceasingly. When tides act upon them, their variations are periodical, and follow the laws which regulate the tides; that is to say, the spring and neap tides, the ordinary, or the equinoctial ones, affect the river-waters in the same manner that they do those of the sea.

5. The speed of a river, or its rate of flow, would continually accelerate, independently of the variation in the volume, if the muddiness of the waters, and their friction upon the bottom and sides of their bed, did not exercise a retarding influence. These resistances augment in proportions even more considerable than the rapidity of the current, and thus counterbalance the influence of the fall, and establish something like a uniformity of flow. It is also to be observed, with regard to the course of all rivers carrying them through plains, that in the latter portion of their passage to the sea the velocity becomes to a great extent equalised by the diminution of the rate of fall.

6. Moreover, the flow is not the same in the whole of the transverse section of a river. In the cases where tides do not act, it is the greatest in the portion called by continental Engineers the *thalweg*, which, in fact, is defined by this identical phenomenon. Beyond the thalweg there are zones in which the water is either stagnant, or even at times when it has a movement in an opposite direction to the usual current, especially in the cases where the section of the river widens out unexpectedly. These currents are sometimes called 'backwater,' or counter-currents. A very plausible explanation of them has been given by Venturi, in a very remarkable treatise upon 'the lateral Communication of Movement to Water.'

Mean Velocity.

7. In the thalweg itself, also, the flow is not the same at the bottom as it is at the surface of the water. In rather shallow rivers, the maximum of speed appears to be at the surface. It is usually considered that the average speed of the filiaments of water flowing uniformly in the same direction is $\frac{4}{5}$ths of that of their surface. This proportion was ascertained by the researches of Dubuat and De Prony. Navier, moreover, observed that when water moved in straight lines parallel to the axis of the bed (supposed in this case also to be straight), the mean speed and the maximum speed of the surface of the thalweg approached each other in proportion as the bed became less, and without any reference to the transverse section. If the vertical depth of the water were very small, and the width very great, he found that the mean speed was 0·64 of the maximum, or surface velocity. If both were very great, the mean speed assumed the proportion of 0·41.

Velocity of Stream.

8. It rarely happens that we meet with rivers whose beds fulfil the requisite conditions of being thus in a perfectly straight line. For all practical purposes, then, we may adopt, for all speeds of water between 8 feet to 5 feet 8 inches per second, measured upon the surface, the following formula as representing the average speed: $v = \frac{4}{5}\,V = 0{\cdot}8\ V$; in which v = the mean or average speed, V = the speed upon the surface. The above formula gives results which are superior to those we meet with in reality, when our examinations are made upon large streams; for the Seine has an average speed in which $v = 0{\cdot}62\ V$; the Neva, $v = 0{\cdot}75\ V$.

Velocity at Bottom.

9. Dubuat's experiments shewed that the speed of the water at the bottom, or immediately upon the bed, may be expressed thus, making U = the speed sought,—

$$U = 2v - V;$$

or, supposing $V = 1{\cdot}25\,v$, $U = 0{\cdot}75\,v$, or $v = 1{\cdot}33$ U.

The consideration of these questions is of the utmost importance to the Engineer about to carry into effect works either for the improvement of the navigation, the defence of the banks, or the construction of bridges. In order to guard against the corroding effects of the current, it is necessary to construct the foundations of the works in such a manner, and of such materials, as are not likely to be removed by it. It becomes, in fact, necessary that the bottom of the waterway should be of a nature to resist the power of the stream to carry off the materials of which it is composed.

10. Experiments have shewn that the different substances named below are carried forward by waters flowing at the respective speeds mentioned in connection with them:

Soils moved.

	Speed per second. ft.	in.
River mud, liquid earth, &c.	0	3
Brown pottery clay	0	$3\frac{1}{4}$
Common clay	0	6
Yellow sand, loamy	0	$8\frac{1}{2}$
Common river sand	1	0
Gravel, size of small seeds	0	$4\frac{1}{4}$
,, of peas	0	$7\frac{1}{8}$
,, of beans	1	$0\frac{1}{2}$
Coarse ballast	2	0
Sea shingle, about 1 inch diameter	2	2
Large shingle	3	0
Angular flints, size of a hen's egg	3	3
Broken stones	4	0
,, agglomerated, or soft schistose rocks	4	4
Rocks, with distinct layers, 'flakey' rocks	6	0
Hard rocks	10	0

It may be observed that very moderate speed enables the water to carry off the lighter soils, such as are usually found in the beds of rivers; and hence, to a great extent, the frequent changes they are subject to. The destructive action of the current is augmented by the beating of waves, the abrasion by floating ice, the alternations of wetness and dryness, and especially by frosts. Aquatic plants protect the beds in a very sensible manner, however, when the depth of water does not exceed much more than 6 feet.

Obstacles to Flow

11. Any unusual obstacle opposed to a current, whether naturally or artificially, acts by heaping up the waters on the up-stream side, and by accelerating their speed on the down-stream side. If the bottom be of a nature to yield to this increased speed, an excavation is necessarily formed. When one of the banks of a river yields to the action of the current, the elbow thus formed has a tendency to increase rapidly. The depth of the water augments, and the currents deposit the matters they hold in suspension upon the opposite side, which becomes gradually convex whilst thus silting up. The curves or beds formed in this manner advance gradually from the up-stream direction to the down-stream.

M. Defontaine observed that upon the Rhine, a river with a bottom of sand and gravel, exposed to sudden floods of remarkable violence, the natural bed of the river

was not affected by the formation of new elbows, when the radius of its curvature was above 8300 feet; at least not to any serious extent. His experience led him to adopt one-half of that radius for the works in masonry he constructed to defend any advanced parts of the banks, in order to protect them against the corroding action of the current at their feet.

Action of Irregularities in the Bed.

12. Any sudden depression, any abrupt projection, either upon the banks or even in the bottom, produces a species of whirlpool and backwater, attributed by Venturi to the lateral movement of the waters. If the bottom should be susceptible of being carried away, excavations would be formed in some places, the materials of which would be deposited at distances, varying of course according to circumstances. We find also that the meeting of two rivers, of the same volume and speed, at an angle nearly of 90°, not only produces an oblique final movement compared with the direction of the primitive current, but also a series of these whirlpools.

Action of Spurs.

A spur projecting into a river also determines a backwater both upon the up-stream and the down-stream side. If the bottom be soft, the point is liable to be undermined and carried away; a silting up takes place in the down-stream angle of the spur, which also sometimes takes place on the up-stream side. This, however, more properly belongs to that portion of the subject which treats of the defence of the banks of rivers.

Action of Floods.

13. Another very important cause of peturbations in the ordinary course or flow of rivers, is found in floods, which, from their velocity and the immense volume of water they bring down, often affect the bed and the sides of rivers in a dangerous manner. Sir C. Lyell mentions one flood in which the waters attained a velocity of no less than 36 feet per second. Such catastrophes are rare, it is true; nor can all the science of the Engineer guard against their effects. But such rivers as the Rhine are known to have risen 66 feet in a single day, and Engineers may often be called upon to resist the action of such floods. These are generally charged with the maximum of foreign matters they are able to hold in suspension. When their intensity diminishes, or the speed of the current is slackened by any accidental circumstance, the waters deposit gradually, and in the order of their specific gravities, the substances they contain. A different relation is thus established between the section of the river, the volume of the water, the speed, the fall, and the form of the outline of the bed. Towards the down-stream portions of the river, the section will be found to have become less able to carry off another flood; and if the sides resist less than the bottom, the river will spread out, often into several branches, which, in the dry seasons, will not present a sufficient depth of water.

Banks at Mouths of Rivers.

14. In the lower portions of a river, where it falls into the sea, there are other causes for the silting up of the channel in addition to those already mentioned. Thus the sea-waters carry up with the tides shingle, sand, or mud, according to the prevailing winds, or the agitation of the sea acting upon the rocks forming the coast. These matters, as well as the alluvium of the fresh water of the upper countries, are deposited when the speed of the currents is arrested by slack tides; and it is thus that in such rivers as the Thames, the Seine, the Loire, the Rhône, the Rhine, or the Po, the channel of the embouchure continually shifts about amongst the numerous banks. It is now held that in many positions the alluvial matters brought in from the sea exceed in volume those brought down from the uplands; so that there is a natural tendency in all embouchures so circumstanced to silt up. The Seine, Rhine, Thames, Orwell, Humber, &c., are supposed to be thus circumstanced.

Raising of Bed.

15. The natural tendency of rivers to raise their beds by the gradual deposition of the matters they contain in suspension also of necessity raises the mean level of their usual flow, and requires that their embankments should also be raised in the

same proportion. The banks of the Po in this manner have been gradually raised until they are from 40 to 45 feet above the surrounding country. Notwithstanding all the precautions taken to preserve them, they must inevitably yield, sooner or later, to the action of the stream; which will create for itself a new course to the Mediterranean, to be in its turn silted up and abandoned, like its predecessors. Such deviations in the bed of the Po are far from rare, even in historical periods; and similar causes appear to produce analogous results at the embouchures of such rivers as the Ganges or the Mississippi.

Natural Barrages or Dams.

16. In addition to the multitude of these causes which tend to modify the beds of water-courses, we may observe that, especially in rivers which flow over gravel or sand, instead of following an uniform law in the diminution of the fall and the speed from their source to the sea, there are alternately zones of still water, in which the speed is hardly perceptible, and in which there is a great comparative depth of water; or 2ndly, there are rapids or shallows, generally placed near the bends of the rivers, where the inclination of the bed, and the speed of the current, are considerable, and where there is but a small quantity of water. These shallows form, in fact, natural barrages, which raise the plane of the waters in the direction of the up-stream. In some cases they are occasioned by projecting portions of rock, which have given rise to the formation of banks in the channels.

Gauging a River.

17. M. de Prony's formula for ascertaining the volume of water in a river, $v = \sqrt{0{\cdot}005163 + 3233{\cdot}428\,RI} - 0{\cdot}07185$, or more simply $v = 56{\cdot}86\sqrt{RI} - 0{\cdot}072$, may serve in gauging any stream, provided we can find a portion of its length, at least 400 yards in extent, in which the section is constant and the inclination uniform. A transverse profile gives the section of the water, and the outline of the water edge of the bottom and sides, the 'perimètre.' From these elements we can easily ascertain the mean radius of the perimètre R. The fall upon the line of the axis is expressed by I. Substituting the values of R, I, and v, obtained from actual observation, we arrive at the volume discharged. In all these formulæ, unless especially mentioned to the contrary, v represents the mean velocity of the current.

Another method of gauging a river is to determine simply the maximum speed at the surface. This is ascertained by a series of observations to be frequently repeated upon floats thrown into the stream, and allowed to travel as far as possible in the part of the river where the current is most regular. The mean speed of the surface thus obtained multiplied by 0·8 gives the average speed of the whole volume. The average section is then taken from as many profiles as possible, and the mean speed of the whole volume multiplied by the surface thus found gives the average discharge. This means of ascertaining the discharge is only approximative; it is therefore advisable to establish the results upon as great a number of carefully-noted observations as possible.

Classification of Rivers.

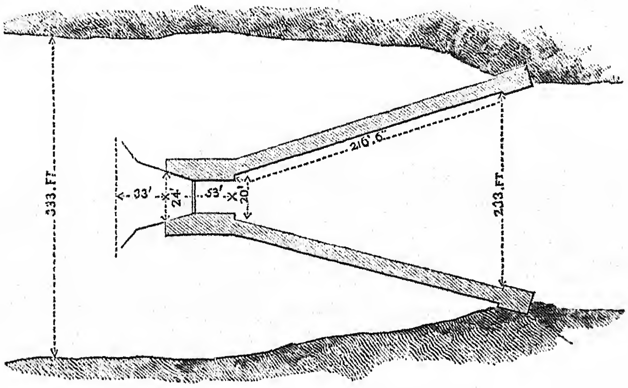
18. Rivers may be divided into two classes, viz. navigable or floatable, according to their adaptation to the wants of commerce.

A river is said to be 'floatable' when rafts of fire-wood or of lumber can habitually meet with a sufficient depth of water, and a sufficient width of section, to descend either by the natural course of the river, or by retaining the waters in artificial basins, from which they are allowed to escape at regular intervals. In England we rarely have occasion to use rivers in this manner; our timber-forests are so few, and so peculiarly situated, as not to require the imperfect navigation in question; but in our Colonies it would doubtlessly be often advisable to direct attention to rendering the mountain streams useful by regulating their flow. An excellent example of the manner in which a shallow irregular river has been made to render service to the kind of navigation under consideration, is to be found in the Yonne, above Auxerre.

Dams and Sluices in floatable Rivers.

19. A series of dams is thrown across the river, which keeps up the waters in a manner forming a set of locks of still water, in which the trains of wood are formed, and floated to the sluices placed in the dams. The sluices are opened in proportion to the supply of water.

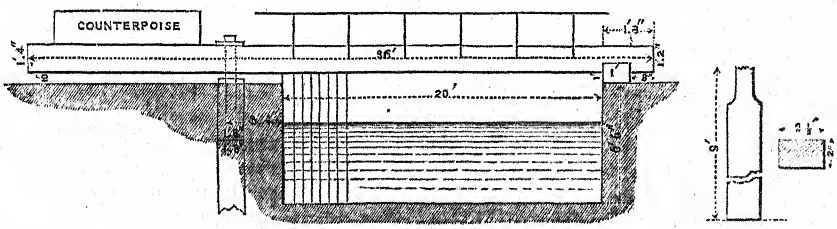
Fig. 1.



Plan of Dam at Régilbert, on the Yonne.

The sluices are mostly formed of small blades of wood, about 9 feet long by 2 inches wide and 2½ inches deep. They fit against a groove in the bottom sill of the waterway, and against a locking bar which turns on a pivot. When it is desired to use them, the lock-men draw the bars one after another, and turn the locking bar aside, which operation is effected in less than eight minutes, provided the opening does not exceed 26 or 27 feet. The width of these sluices is made from 1 foot 4 ins. to 2 feet more than that of the trains or barges to be passed; and the walls should splay out immediately above and below the passage, with an estacade to defend the entry. These sluices have falls varying from 2 to 4 feet, but the latter is dangerous; their floors in the passages should be from 28 to 34 feet long. It is essential to observe that both the floor, and the walls in prolongation, require to be defended by piles and sheeting piles; for the opening of the sluice invariably causes a cataract.

Fig. 2.



20. The best position for the sluice is in the centre of the dam, as far as the preservation of the works is concerned; but for the purposes of navigation it is desirable to bring it as close as possible to the towing-path. The waterway should be contracted also for a distance of from 350 to 500 feet beyond the end of the floor. If it be necessary to combine a lock with the sluice, a circumstance very likely to arise when the river, after receiving several affluents, begins to acquire a considerable

volume, the lock must be placed in still water on the opposite bank to the sluice. This last must be at the head of the chamber upon the upside of the lock, which it is desirable to place at a distance of about 80 feet from the end of the dam. Care must be taken to protect the side and tail walls of the lock from the cataract produced by the sluice.*

It is to be observed that dams across a river affect its level to distances considerably beyond the point where the line of their crown meets the line of the natural flow of the water. They appear, by retarding the velocity of the current, to heap up the waters anormally in a proportion which augments with the rapidity of the flow.

Navigable Rivers.

21. A river is said to be navigable either by means of sails, by the use of oars, or by towing. Navigation may take place either upwards or downwards; but in either case the river should offer sufficient width and depth of water for the movement of boats. There is, however, a limit of velocity in the current beyond which there is danger for the descending navigation, and excessive expenditure of power for the ascending.

Navigation by sails can rarely be practised in rivers, owing to their want of width and depth, their windings, and to the fact of their being usually enclosed in deep valleys. Towards the mouths of the rivers these unfavourable conditions disappear, and we find that in such rivers as the Thames below the bridges,—the Seine between Rouen and Havre,—the Loire between Nantes and the sea,—the Garonne between Bordeaux and the sea,—navigation by means of sails takes place under tolerably favourable conditions.

The force of the wind, even when favourable, is rarely employed in ascending rivers, unless the speed be below that produced by a fall of at most 3 in 10,000, with a feeble width and a comparatively great depth of water.

22. The utmost limit of the fall of the bed of a river at which it was formerly considered safe to descend, or economically possible to ascend, was when it attained from 5 to 6 in 10,000. The progress of mechanical invention has, however, modified the practice of commerce in these matters; and at the present day the Rhône, which has a fall of from 7 to 8 in 10,000, is navigated with advantage. The River Lys in Belgium, upon a certain portion of its length, has a fall of about 5 in 10,000, in the district where the navigation is very active. It is supposed that in this case the aquatic plants, which it is forbidden to cut, act so as to retard the force of the current.

The boats used in commerce for River Navigation are of variable widths, from 6 feet 6 inches wide to 23 feet upon large rivers; with a draught of water varying from 2 feet to 6 feet 6 inches when loaded. Their length is of course regulated by the sinuosities of the channels and the width of the waterways, and it is often carried as far as twelve times the breadth. On some of the continental rivers it is very common to see barges 233 feet long by 23 feet wide, drawing 6 feet 6 inches of water, and able to carry 500 tons. Such enormous vessels are not in use in our own country, for the flow of the tides upon our coast usually runs so far inland as to obviate the necessity for transhipment immediately upon the sea-board, under which circumstances the large barges in question are the most economical. It were desirable, however, that the barges to be employed on our East Indian rivers were constructed somewhat upon the models of those used upon the Lower Seine, or upon the Loire.

23. We see thus that a river may be navigable by different means, according to the way in which we consider it; that is to say, whether in the ascending or descending direction, the draught or the tonnage of the boats employed, or the total length

* The minimum width of a floatable river is 13 feet; its minimum depth at the moment of flashing should be 1 foot 8 inches.

of time in the year during which it is navigable. In the latter case, it often becomes necessary to make a deduction for the low, or for the flood, waters. The first do not leave a sufficient depth of water for the boats to be able to travel; the latter often give rise to such velocities of the currents as to render it dangerous to navigate the rivers.

24. The movement of boats upon rivers is effected in the direction of the ascent, either by the oar, by towing, by animal force or by steam power applied in various ways.

Effort of Traction.

A horse is supposed to be able to exert upon a good Macadamized road a force of traction equal to twenty times the muscular effort employed. This is assumed to be equal to one hundred weight, so that his load on a road of this kind, while moving at the rate of about a yard per second, is one ton.

On a paved road the load becomes one ton and a quarter.
On a railway it is about ten tons.
Whilst in still water it is sixty tons.

On the Meuse, the power of a horse drawing against the stream, flowing at the rate of about 3 feet per second, with a depth of water of 3 feet 4 inches, and a discharge of 1225 feet cube per second, was found to be equal to 25 tons when moving at the rate of two miles an hour.

Experiments made on the canals of the North of France, in still water, shew that the resistance is about 0·0006 of the load, when the rate of movement is 3 feet 4 inches per second. On the canal of Givors, where men haul at the rate of 1 foot per second, the resistance is only 0·00014 of the load.*

25. Formerly it was considered that the resistance increased in the ratio of the square of the velocity; but Mr. Scott Russell's experiments upon the Caledonian Canal appear to shew that this law does not hold good when the velocities exceed from 10 to 13 feet per second. The explanation of this apparent anomaly is usually found in the facts,—that in great speeds the surface exposed to the resistance of the water was diminished,—that a void was formed at the after-part of the moving body, and that the velocity of the water rushing back to fill this void was less than the speed attained by the hauling. Mr. Russell also noticed that the water was heaped up in the form of waves in front of the boat, and that these waves carried it, in fact, over passes where there would not have been, otherwise, a sufficient depth of water.

The laws thus discovered, without, however, our having obtained any satisfactory explanation of them, were endeavoured to be applied both in England and France. The success of their commercial application has been hitherto very equivocal, for the backwater and the beating of the waves upon the banks necessitated the paving of

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* The effort necessary to draw a boat for an indefinite length through still water is represented by the formula

$$F = K\frac{A\,V^2}{2g}; \text{ in which}$$

F is the force of traction represented in tons.
A is the greatest width of the sunk surface.
V is the speed of the boat per second.
K is a coefficient, varying with the form of the boat.
g is the accelerating force of gravity.

The coefficient K may range from 1·10 to 0·12, according to the sharpness of the bows of the boat, or the presence or absence of a poop. In a canal, inasmuch as the section of the boat is greater in proportion to that of the water surface, the relative velocity of the current on each side of the boat is increased, and consequently the motive power requires to be augmented in the same proportion.

the latter by dry pitching, at least wherever the level of the waters was displaced by the movement of the boats. It also became necessary to macadamize the towing-path, to allow the horses to travel at the requisite speeds. This question will, however, be treated more in detail under the head of Canal Navigation.

Position of Towing-path.

26. In River Navigation, the towing-path should be placed on the side where the water is the deepest, and immediately upon the banks of the river; in order that, firstly, there may be as few impediments to the passage of the cords as possible; and secondly, that the direction of the haulage be not too oblique.

It is also desirable to place the towing-path under the prevailing wind, in order to diminish as much as possible any action it might have in retarding the progress of the boat. The best width for a towing-path appears to be about 13 feet.

Independently of the towing-path, it is necessary to have mooring-posts on the opposite side of the river; and occasionally it is necessary to haul on both sides of the river, to maintain a boat in the navigable channel. It becomes then indispensable to have a kind of secondary towing-path on the opposite side, which, however, need only be 6 feet 6 inches wide on the crown. Both these paths must be maintained at sufficient heights to keep them above the water so long as the navigation can be carried on with safety. When that would be accompanied with danger, it is rather desirable that the paths should be overflowed, so as to force the boatmen (always reckless) to suspend their operations.

27. In the construction of Bridges, it is desirable that the towing-path should pass under the land arches in such a way as not to render it necessary to detach the tow-rope. But in order to effect this, it is indispensable that the navigable channel should be near to the towing-path. Should this not be the case, it becomes necessary to let in rings, or to drive in mooring-posts, or to place buoys at the opening of the arches, to fasten the boats to whilst the tow-rope is being passed through the bridge.

Any secondary streams intercepting the line of the towing-path must be bridged over in such a way as to offer no obstacle to the tow-line.

Works for the Preservation of the Banks and of the Bed of Rivers.

28. These are of two descriptions: sometimes they are intended to preserve the neighbouring lands from the corrosions of the stream; sometimes for the purpose of maintaining the latter in its proper direction, and at a regular distance from the towing-paths. The dredging works required for the purpose of clearing the alluvial deposits may be included in this category.

In rivers which run with great velocity, such as the Rhine, the Rhône, and the Dordogne, these works are of the very highest national importance. In some cases the rivers run between the territories of nations often at war with each other, as in the case of the Rhine; at others they traverse consecutively several states, as the Danube or the Po. The lower Rhine, whose floods formerly spread themselves over nearly the whole width of the valley in which it flows, has been gradually confined within its present bed by a series of embankments about 10 feet wide on the crown, which are disposed occasionally in several nearly parallel lines; so that if one embankment gave way, its ruin would only affect the portion of land it immediately protected. The banks of the Loire, between Orleans and Angers, answer the same purpose; although, from the fact of their being only single, some serious devastations have resulted from their rupture.

The overflowing of the freshets of such rivers as the Rhine, the Rhône, and the Loire in France, and of the Arno and Po in Italy, of the Nile in Egypt, have produced the following result: viz. that the zones in the immediate proximity to the river are

generally more elevated than those which are farther removed and upon the extreme edge of the valley. This is to be accounted for by the fact that the great floods deposit near to their banks the heaviest and most voluminous matters they hold in suspension, and that they are far less loaded when they spread out over the plain. From this cause marshes are eventually formed; because the rain and spring water, being unable to flow into the river channels, remain upon the surface of the land.

29. One of the cheapest, and at the same time it is one of the most effectual methods of protecting the bed of a river, is by means of planting aquatic trees, such as the willow, &c., on both its banks. The roots of these trees spread very rapidly, and in themselves form the first defence of the bed of the river, as also of the banks. At the same time, inasmuch as they retain the mud which may be in suspension, they serve also gradually to raise those parts where they are planted. It is, however, necessary to execute such plantations on both sides at once; otherwise the defence of one side will but serve to increase the force with which the waters attack the other.

Rectification of Midouze.

A very remarkable work of this description, which, it may be added, has been attended with signal success, was that executed for the purpose of rectifying and regulating the bed of the Midouze, between the Port de Marsan and its embouchure in the Adour, for a distance between 25 and 26 miles. The width of the pass created varied between 71 feet and 91 feet; the variations in the width being equally, or nearly equally, divided into four parts; and the limits of the new bed of the river were comprised between two concentric curves.

The original bed of the river was very wide and irregular, being formed in the midst of movable sand-banks, through which the waters found a channel shifting almost at the caprice of every wind. The waters of the Midouze, even in their normal state, carried down great quantities of mud and sand. The system adopted was, to form spurs in a kind of wattling, which were connected at one end with the bank, and at the other projected into the stream as far as the line of the intended new channel. These spurs were inclined at an angle of $\frac{1}{10}$ of that formed by the line of the current with the axis of the new bed.

The spurs were placed at distances of 133 feet apart, and exactly opposite to each other when they were to be fixed to the banks on both sides. They terminated towards the stream by returns in the shape of the letter T, each of whose branches was about 17 feet long.

The spurs were formed of pickets, placed 1 foot 8 inches from centre to centre. These pickets were of willow, of from $3\frac{1}{4}$ inches to 5 inches diameter; they were driven at least 4 feet 6 inches into the ground, leaving 1 foot clear above the level of the ordinary low water. Between these pickets, a wattling of 3 feet 4 inches mean height was executed with branches of willow between 7 feet and 10 feet in length, and about 1 inch in diameter. They were kept in their places in the upper part, so as to prevent their rising during floods, by means of oak plugs driven through the heads of the pickets. Long poles, about 10 feet in height, were placed on the opposite side to the towing-path, to indicate the waterway.

Independently of these main spurs attached to the banks, two minor spurs, about 42 feet 4 inches from centre to centre, with returns measuring 33 feet over both branches, were inserted between the main spurs. The object of their insertion was to facilitate the deposition of the mud and sand, and thus prevent the backwater from overthrowing the main spurs.

The minor spurs were composed of young trees of from 4 to 6 inches diameter; the length of the trees and their branches was not less than 10 feet; the diameter of the branches 5 feet. They were sunk in such a manner as to present their trunks

constantly towards the pass, so as to direct the currents towards the new channel. Their direction was the same as that of the main spurs, that is to say, at an angle of $\frac{1}{10}$ of the one formed by the axis of the river, or new bed, with the current. The trees were fixed at distances of 10 feet apart. Strong pickets were driven in through the branches, so as to form an additional tie, to which the trunk of the next tree was attached. Of course the pickets followed the inclination of the first range of trees, and strong oak pegs were applied to prevent the branches from rising too far on the occasion of floods.

30. A pass, or waterway, was dredged between the main spurs above described, to a depth of at least 1 foot below the lowest summer waters, and all the sand or mud thus extracted was thrown between the different spurs in such a manner as to add to their stability.

As soon as an artificial bank was thus formed by means of the excavations of the pass, and the gradual deposition of the matters in suspension in the waters of the river, means were adopted to defend it by plantations consisting of slips of willow, osier, poplar, or other aquatic trees, placed at distances of 6 feet 6 inches apart, and inclined so as to break any current which might be formed beyond the regular pass. Heath and grasses were planted between these in such quantities that 1 lb. of seed was used per acre. The slips of all the trees, except the osiers, stood about 6 feet from the ground; these last only stood up about 8 inches.

This method of forming the bed of the Midouze succeeded remarkably well, and was carried into effect at comparatively trifling expense. In many of our Colonies a similar system might probably be advantageously adopted. A detailed account of this work will be found in the 'Annales des Ponts et Chaussées' for the year 1831.

31. The effects of the action of running water upon different beds are, however, so various, that what is highly successful in one case becomes utterly ineffectual in another. For instance, in the Loire, transverse spurs, even when executed in solid masonry, fixed to one bank and advancing far into the stream, produce very uncertain effects upon the width of the waterway. The excavations they form on one side are, in fact, very often accompanied by silting up on the other, or at points a little lower down the stream on the side attacked, so that the bed they create is very irregular and unequal. Indeed, as a general rule, it may be said that the only certain mode of deepening the bed of a river is by the establishment of longitudinal enbankments either submersible or not,—continuous, or with small openings, to allow the passage of flood-waters, according to the local peculiarities of the river to be acted upon. A knowledge of the modifications to be introduced in the application of these general rules constitutes, in fact, nearly the whole merit of an Engineer.

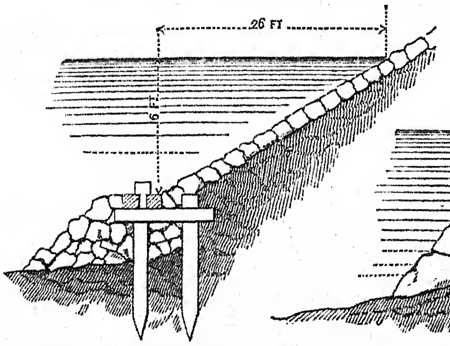
32. Continuous banks are executed in many different ways, according to the nature of the soil, the course of the river, and, above all, according to the nature of the materials to be met with the most readily, and at the cheapest rate. On the Continent they are executed sometimes in rough blocks of stone or concrete; of fascines, or of panniers in osier, filled in with gravel or rubble-stone; or lastly, by a combination of the above methods, which answers very well for the immersed parts of the bank, when the portions out of water are dressed off to a regular slope, and planted, or paved with a dry stone pitching, laid in either regular or irregular courses.

Embankment Walls.

On the banks of the Loire the slopes are protected by means of stone pitching, which is remarkable for the perfection of its execution and its comparatively feeble thickness. They are generally inclined in the proportion of $1\frac{1}{2}$ of base to 1 in height. A bed of gravel is placed behind them, and the foundations are merely formed by an excavation or trough dug in the sand below the level of the mean summer waters, subsequently filled in with rough rubble masonry. At times, however, it has been

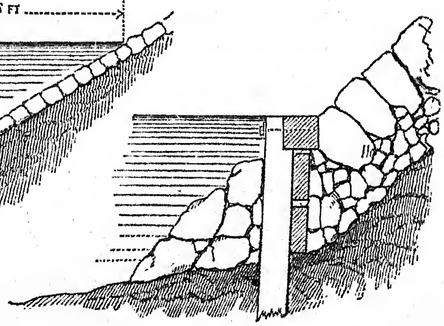
ound necessary to introduce gauge-piles with longitudinal wales, as shewn in figs. 3 and 4.

Fig. 3.



Embankment on the Loire, near Amboise.

Fig. 4.



Foot of the same on a larger scale.

Occasionally also the inclination of the slopes is increased to 2 of base to 1 in height. The thickness at the top is made between 8 inches and 1 foot. The augmentation in the thickness is usually about 3 inches for every 3 feet 4 inches in height.

Timber Walls.

33. A timber walling often suffices for the protection of a bank of a river, and affords means of diminishing the width of the stream. An example may be taken from the artificial channel made in the Port of Lorient. But it may be observed that

Fig. 5.

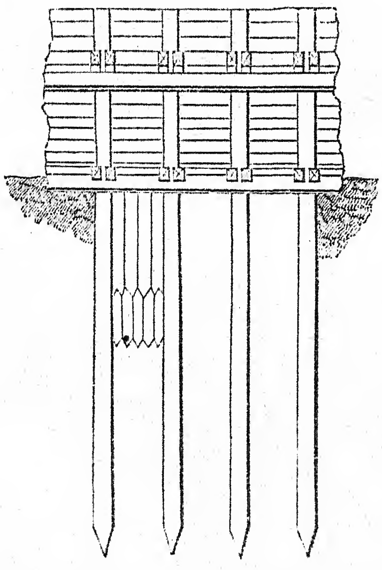
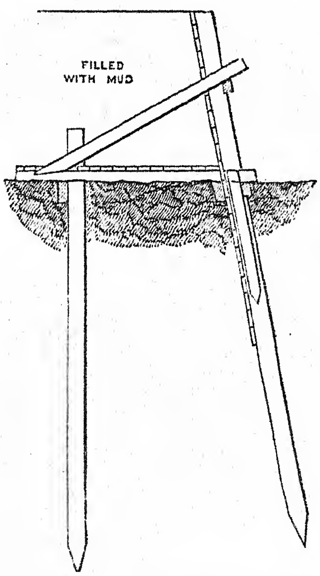


Fig. 6.

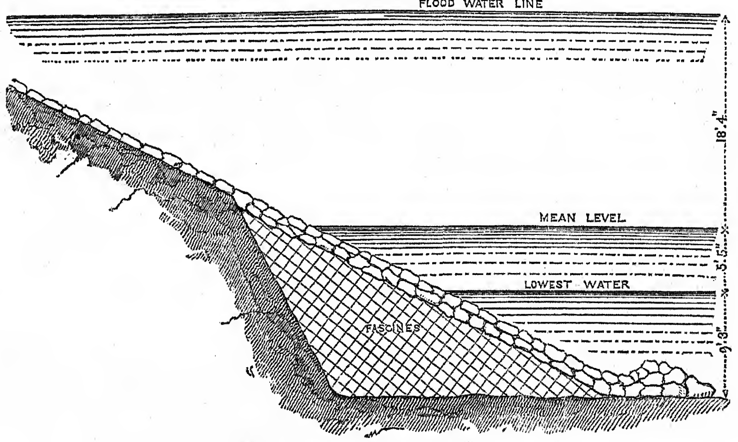


the gauge-piles in such works require to be driven to very considerable depths; and that if the waters have what is technically called any scour, the solidity of banks thus made is more than questionable.

Mixed System on the Rhine.

34. On the banks of the Rhine and in Holland, the high price of stone, combined with the unlimited supply of gravel and aquatic trees, have led the French, German,

Fig. 7.



Mixed System used on the Rhine.

and Dutch engineers to substitute either a mixed system of fascines paved with stone, or what they call 'tunages,' instead of the system employed in the countries where

Fig. 8.

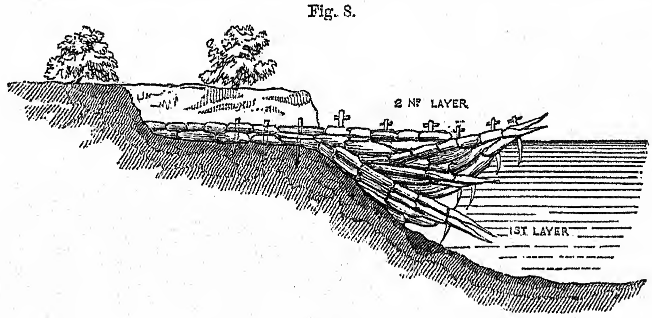
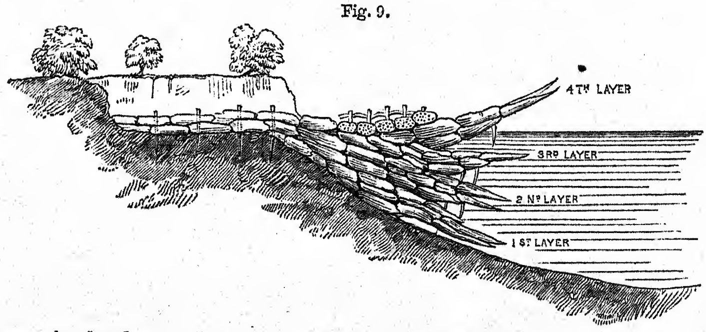


Fig. 9.



stone is abundant. Works for the defence of the banks, or for the regulation of the waterway, executed in this manner, do not, it is true, last very long; but their

relative duration is sufficient in rivers carrying much suspended matter; for they give rise to depositions which eventually serve to effect the object intended in a more permanent way.

Tunages.

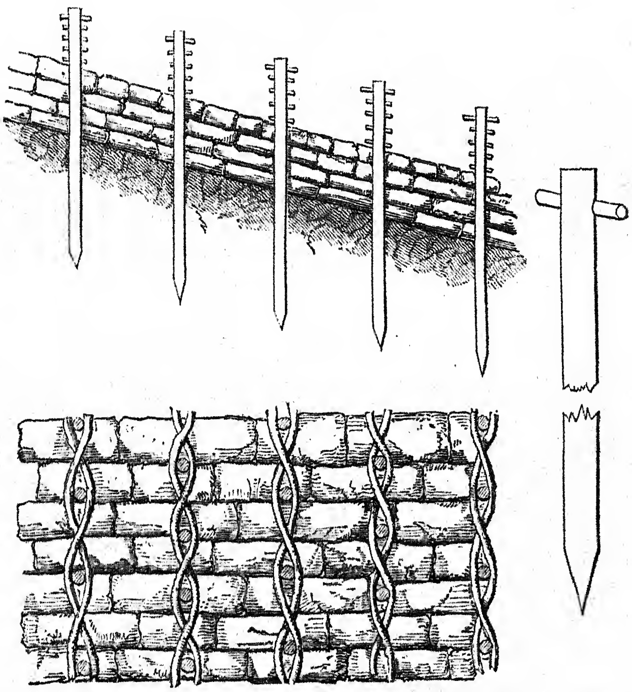
35. The tunages upon the Rhine consist, in the portions submerged below the level of the low summer waters, in floating layers of fascines, which are firmly fixed in the bank, and sunk by being loaded with gravel or rubble-stone. These layers of fascines are fastened, either to the bed of the river, or to the subjacent layers, by means of strong pickets. The work is so divided that the beds of fascines float at their extremity towards the river, so as to leave toothings, in case it should become necessary to advance the work further into the waterway or thalweg. The flexibility of this kind of carpet also enables it to adapt itself with more facility to the different forms of the bed. Great rapidity of execution is necessary whenever the tunages are used, in order to avoid the dangerous effects of the scour of the waters under the floating extremities of the fascines.

In Holland, when the banks of a river are attacked by the current, immense platforms are constructed of such tunages, which are floated to the positions they are intended to occupy, and there sunk. Such a mode of proceeding is practicable in a country where the waters may all be said to be sluggish, but when the current attains any degree of velocity, it ceases to be of any practical use.

Clayonnages.

36. The original banks of a river, or any embankment formed for the contraction

Fig. 10.



Clayonnage used in Holland, and upon the Banks of the Rhine in France and Germany.

of its channel, are sometimes defended by what are called 'clayonnages.' This

method consists in covering the surface to be protected by fascines laid transversely to the direction of the current in three or four rows. Strong pickets are driven through them, and are allowed to project about 18 inches above the top. Withes are then passed over the projecting heads of the pickets, and serve to form a kind of frame-work on which stones and gravel are laid, to maintain the fascines in place, and to stop any matters which may be in suspension in the waters. The durability of such works is not great, nor should they be resorted to in positions where stone defence-walls can be erected with due regard to economy.

37. In our own country the use of fascines is almost exclusively confined to the Corps of Royal Engineers. The usually adopted systems of protecting the banks of rivers are limited to modifications of dry stone walling or of timber revetments. On the banks of the Thames some very extensive works have been executed for the protection of the low lands, especially below the bridges; but they may be said to be more remarkable for their magnitude than for the skill or economy of their execution. In fact the extreme regularity of the course of our rivers has so simplified the difficulties connected with works intended to maintain them, that very little attention has been paid to the subject by English Engineers.

Spurs.

38. In many rivers the banks are protected by a series of spurs without return ends, projecting into the stream, and attached solidly to the bank. It was formerly considered that such spurs were more economical than a continuous embankment. In some instances they protect a length on the upper side of double their projection, and on the lower of three times the same length; but they have been found to produce sinuosities in the course of the stream, and to determine strong corrosive actions on the down-stream side; moreover, the heads of the spurs themselves are much exposed to the undermining action of the waters. The dangers of the use of spurs are most strongly developed during floods. In ordinary states of the river, the water which passes into the angles formed by the spur becomes stagnant, or it turns slowly, especially on the up-stream side, and allows a deposition to take place; but when extraordinary floods occur, and the velocity of the stream becomes very great, the rotary motion of the water not unfrequently produces a whirlpool which injures the bank and the works of the spurs themselves. The spurs, in fact, give rise to a destructive action more powerful than the one they were intended to guard against.

New Channels, Cuts, and Dredging.

New Channels and Cuts.

39. In certain rivers whose section is very great, and which are liable to great floods,—whose beds may be said to possess great mobility, and whose central portions are often occupied by islands,—the navigable channel is likely to pass from one bank to the other by traversing the intervals between the islands, and it has been attempted to rectify the bed by creating new channels across the latter.

The practical results obtained by the Engineers of the Rhine (a river which is in all respects worthy to be taken as a model, both from the difficulties it presents, and the skill employed in overcoming them) have led to the establishment of the following rules:

1st. The new channels should be as deep as possible.

2ndly. They must be connected with the old channel by curves of considerable radius.

3rdly. They must not be opened to receive the waters of the river until the down-stream end of the ancient pass has been completely closed. It has been found impracticable to divert the waters into the new channel unless this be done,

because it is impossible to throw out the new cut to a depth inferior to that of the old channel.

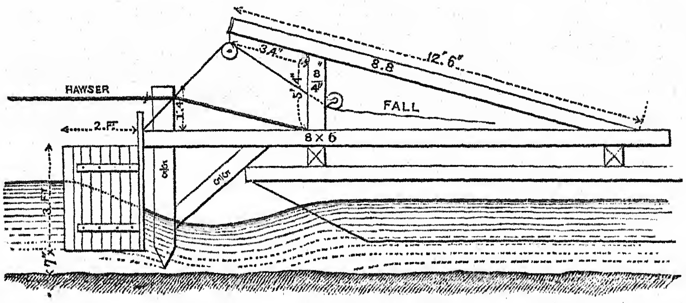
4thly. The beds of the new cuts must be cleared of all trees, reeds, or aquatic plants in the zone in which it is intended that the river should flow.

It has been found that cuts having only between 17 and 30 feet at the bottom, or floor-line, were sufficient for the Rhine, notwithstanding its immense volume. The waters directed into the new cuts do, in fact, very rapidly both deepen and enlarge the channel to the extent necessary to insure the full discharge of the stream.

Dredging.

40. An economical manner of removing the materials of the bed of a river consists in the application of movable dams attached to a boat. These dams offer a resistance to the flow of the water; and, according to the greater or less depression given to them, they either divert the whole effort of the stream against any particular object,

Fig. 11.



or, by simply contracting the waterway, they augment its velocity, especially at the bottom. This mode of dredging cannot be applied if there be any necessity for the removal of the materials disturbed. It evidently only acts by displacing them, leaving them free to be deposited elsewhere. Wherever applicable, this system has been found to diminish the expense by about $\frac{8}{10}$ths.

The machine shewn in fig. 11 was employed on the Garonne, in which river it removed about 60 yards per day of sand and clay, at an expense of about 2¼*d.* per yard cube.

41. In the United States, rocks in the beds of rivers are often removed by means of a series of stampers, set in motion by the waters of the river acting upon wheels attached to boats or any other temporary staging. Sometimes it is necessary to employ the diving-bell, and to blow up impediments to the navigation with gunpowder. At others, and especially when it is desirable to remove entirely all the materials loosened from the bed of the river, the dredging-boat, moved by steam power, is employed.

Natural Bars.

42. Before quitting this subject, it is necessary to notice an interesting fact as regards the beds of rivers. In many cases, particularly in those where the bed is composed of gravel, natural bars form, as it were, of their own accord: if removed, they are re-formed with great rapidity, and appear to result from the form of the bed, which gives rise, in these precise localities, to a sort of slackwater favourable to the settling of the gravel. Advantage should be taken of the indications thus given; for if it be desired to erect a dam or barrage, the positions of these natural bars will be found to be the most advantageous, and the direction they take with the current will also be the one most likely to insure the solidity of the construction.

General Considerations upon Works for the Establishment or the Amelioration of the Navigation in Rivers.

Economical considerations.

43. The solution of the questions connected with the establishment of river navigation is attended with so many difficulties both technical and commercial, whose importance varies with almost every separate case, that it is impossible to lay down any invariable rules to guide the conduct of an Engineer. Local circumstances influence to so great an extent the favourable economical results of such work, that every river requires to be examined, as it were, upon its own capabilities.

When the navigation takes place downwards only, and there is a sufficient depth of water, and when the flow of the water is alone the moving power, the danger to be obviated can solely arise from the too great rapidity of the current. If it be desired to render the river able to float larger boats, its depth can only be augmented by retarding the velocity. The question to be examined before undertaking works to effect this, is whether it be more economical to employ large boats with a longer total passage, or small boats travelling with greater rapidity.

If the navigation take place upwards, works which would retard the velocity of the stream produce not only a great saving in the motive power, but also enable larger vessels to be employed : the question in this case is simply whether the navigation is sufficiently active to justify the expense incurred. But if the navigation takes place in both directions and in variable proportions, the solutions admit of an endless variety.

44. The first considerations which arise, when we examine the necessity for improving a river, are,—shall the navigation be kept in the old channel?—shall a new one be opened, either with running waters, or with still waters as in a canal?—on which bank shall the navigation be maintained? These considerations are moreover complicated by the nature of the country on the banks of the river, the rights of the proprietors, the occasional presence of mills, and even by questions of military defence. Finally, we may meet with physical impossibilities; or, at least, the outlay may be so enormous as not to warrant any hope of success.

Scientific data required.

Before proceeding to lay down any project for the improvement of a river, a general plan must be made of the main stream and of all its affluents. Longitudinal and transverse profiles, and levels of the bed, the banks, and the land immediately upon them must be taken. Careful observations must be made upon the heights of the lowest waters, of the mean, and of flood streams, taking care that they be averaged over the greatest possible number of years; and the volume of the river must be gauged in all the above states. The nature of the matters held in suspension, the tendency of the river to scour, or to deposit, and the nature of the bed, are also points of vital importance. The form, and tonnage, of the boats in use upon the river to be improved, or upon any other with which it communicates, must also be ascertained. The capabilities of the surrounding country for the provision of materials necessary for construction will also require to be noted.

Formulæ of Volume of a Stream.

The formulæ announced by De Prony, and verified by Eytelwein upon some large rivers, are of great service in determining the volume of a water-course. Leaving out of account the form of the banks, they are

$$V = l.\, h u, \ \& \ u = -0{\cdot}07 + \sqrt{0{\cdot}005 + 3233 \frac{l h}{l + 2 h} i},$$

in which V = the volume per second; l = the width of the bed; h = the mean depth; u = the mean velocity per second, and i = the fall.

In rivers whose width is great in proportion to the depth, the value of u may be safely taken as being

$$u = -0{\cdot}07 + \sqrt{0{\cdot}005 + 3233\, i \frac{l}{l + 2}},$$

or even when the width exceeds 130 feet,

$$u = -0{\cdot}07 + \sqrt{0{\cdot}005 + 3233\, i}.$$

More detailed information upon the application of these formulæ will be found in the works of De Prony, Coriolis, and Gauthier, or in the 'Annales des Ponts et Chaussées,' 1835–6.

Effects of Bed.

45. One of the first obstacles to the navigation arises from the narrowness of the stream, either in the straight parts of its course, or in the curves. If it be attempted to remove this obstacle by excavating the sides, we are likely to diminish the velocity, and also, very probably, the depth. Moreover, if the river hold much extraneous matter in suspension, the depositions which will take place in the still waters will probably cause the banks to be re-formed, unless the channel be kept open by continual dredging.

46. Bends in rivers affect the navigation injuriously in two ways. Firstly, they diminish the width practicable for boats, and secondly, they augment the length of the traject. By opening a new passage between the extreme points, the velocity is increased, and simultaneously the depth is diminished. It often happens, if the banks be easily corroded, that at the time of floods the river re-opens its original channel, an accident which occurred on the Oise above Compeigne.

Modes of remedying Defects.

If the bend be of sufficient importance, the best method of obviating it is to construct a lateral canal with locks. Of course it becomes a matter of calculation whether the economical returns of such works compensate for the outlay.

If the nature of the bed or the velocity of the stream be the principal obstacle to the navigation, these may be obviated as follows. Firstly, either by lengthening the course of the river, by widening it, or by deepening it; or by a combination of two or more of the above methods. Secondly, by establishing transverse dams to retain the water, in a series of ponds of still water,* between which communications are established by locks, sluices, or flashing gates, to be subsequently described.

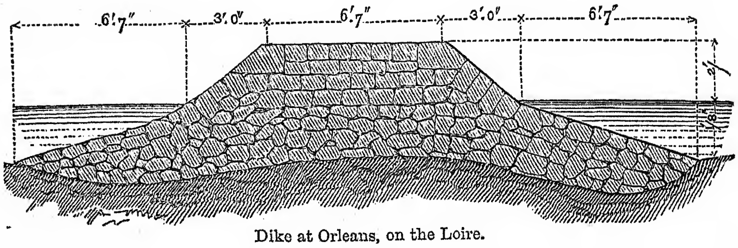
When the want of depth is the principal obstacle, it is sometimes obviated by contracting the channel, either by transverse dikes, or spurs, fixed to one or both banks, or by longitudinal dikes, either single or double. When rivers are divided into numerous branches by islands in mid-channel, the dikes are established in such a manner as to close up the smaller branches, and to connect the islands with one another. Some very important works of this description have been executed on the Loire, between Orleans and Nantes; and also upon the Seine, between Paris and Rouen. These will be described in detail; but it may be here observed, that the results confirm the assertion, "that the only certain mode of deepening a river is by the establishment of continuous longitudinal embankments."

Height of Embankments.

47. The height chosen for the crown of embankments is a subject which requires mature consideration; for upon it depends, to a great extent, the action of the upper floods, and the scouring action of the river. The dikes or dams of the Loire, of the Rhine, and of the Po, when they are executed, as in the latter, at a distance from the bed of the river, do not produce any danger from the causes here mentioned. They are, in fact, only intended to resist the floods, which, on extraordinary occasions, would otherwise overflow the fertile lands at the back of the embankments. It has

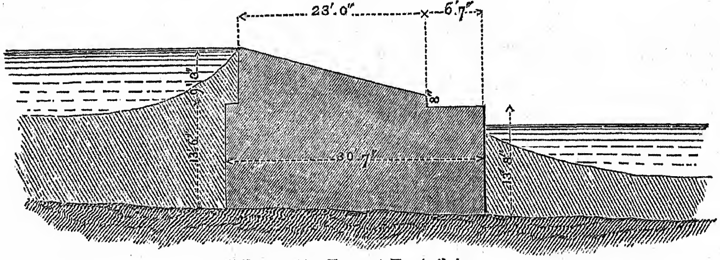
* As on the Rideau Canal, Upper Canada.

Fig. 12.



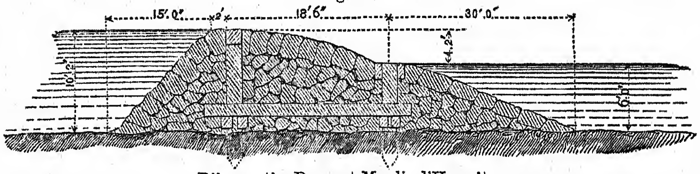
Dike at Orleans, on the Loire.

Fig. 13.



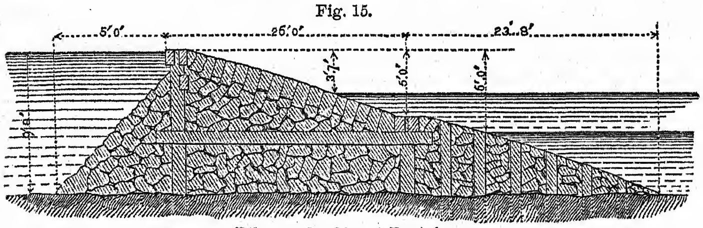
Dike on the Tarn at Fontvilaine.

Fig. 14.



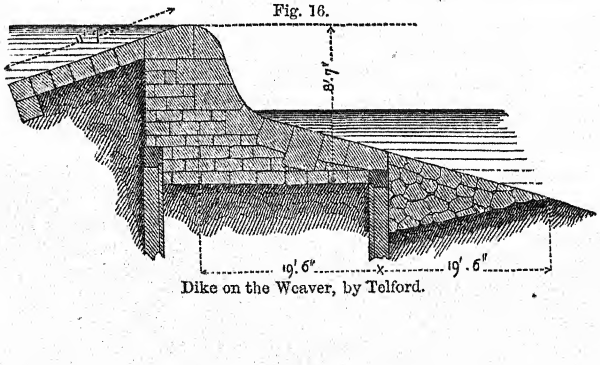
Dike on the Doux at Moulin l'Hermite.

Fig. 15.



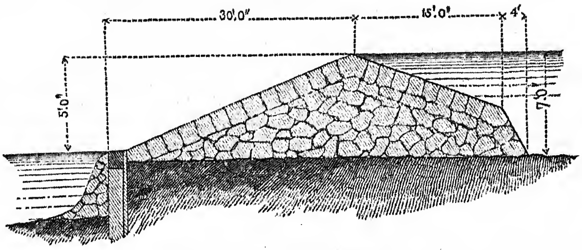
Dike on the Oise at Pontoise.

Fig. 16.



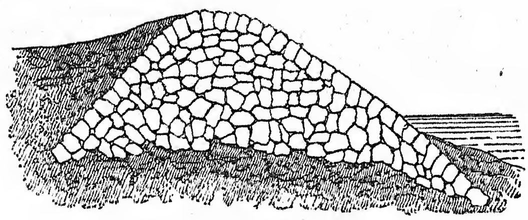
Dike on the Weaver, by Telford.

Fig. 17.



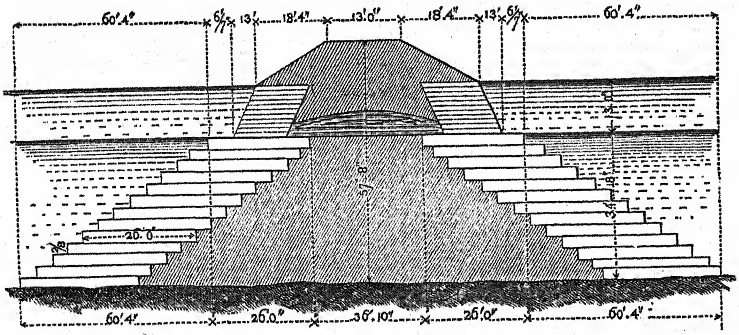
Dike on the Carron, by Smeaton.

Fig. 18.



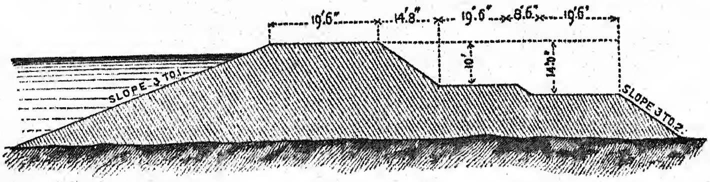
Dike on the Ribble, by D. Stevenson.

Fig. 19.



Dikes to close small Branches of the Lower Rhine, in Holland.

Fig. 20.

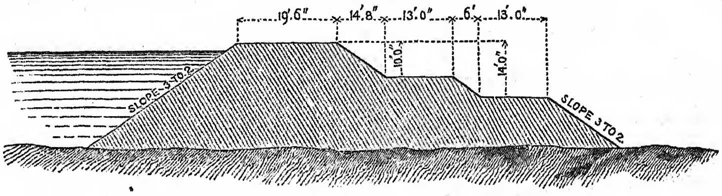


Dike of the Po, 'en froldi,' or close upon the waterway.

been found advisable in practice never to allow the crown of the embankments erected for the purpose of diminishing the channel to exceed the level of the mean waters; whilst they only exceed that of the low waters by about 2 feet, and are covered by the floods.

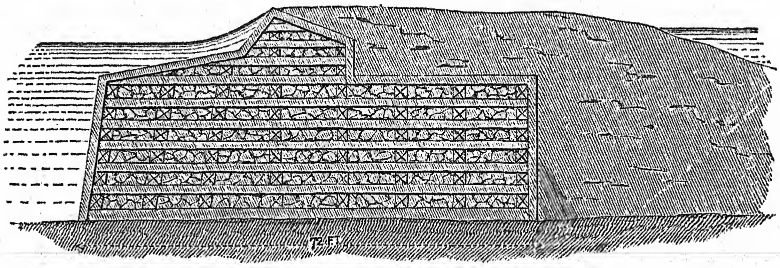
48. The following simple rules suffice for ordinary cases, and they give results which are tolerably accurate. 1st. The velocities vary in the inverse ratio of the cube roots of the widths. 2ndly. The cubes of the heights are in the inverse ratio of the widths of the beds. In the United States, the principle adopted to regulate-

Fig. 21.



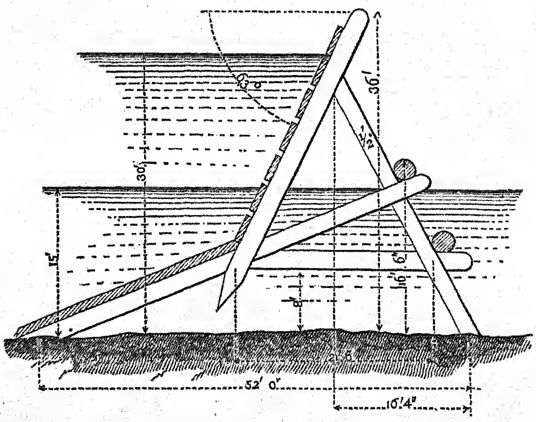
Dike of the Po, 'en golene,' from 1 to 3 miles from the river.

Fig. 22.



Dam across the Hudson, near Albany, U. S.

Fig. 23.



Magistrini's Temporary Wooden Defence-walls, applied upon the banks of the upper Po, in Piedmont. They were executed in round timber, planked to the first bend with close planking, and the boards above were laid with a space between.

the dimensions of the narrowed pass is, to make its capacity equal to that of the ancient bed. As much as possible it is requisite to preserve the natural waterway; and if it be necessary to displace it at all, to direct it, in preference, to the bank or portion of the channel most likely to yield to the deepening action of the waters.

Dikes or Dams in Tidal Portions of Rivers.

49. Longitudinal dikes appear to be indisputably the form most fitted for the tidal portions of rivers, inasmuch as they allow the tidal waters to spread with greater regularity. On the Clyde, the Dee, and the Ribble, it was attempted to deepen the waterway by means of transverse spurs, or jetties; but the experience of the best Engineers has led to the substitution of the longitudinal dikes. These are, in the cases referred to, executed in rubble-stone, and are usually from 3 to 5 feet above low-water mark. When covered by the tide, their position is indicated by beacons placed at regular intervals. Some very interesting information upon the subject of the improvement of the tidal portions of rivers is to be found in a short work by D. Stevenson, Esq., published in 1849. The Report made by Messrs. De Prony and Sganzin, in the year 1806, upon the works projected by the order of Napoleon for the restoration of the Port of Venice, contains also very valuable observations upon the best method of improving tidal rivers.

The materials employed in the execution of these jetties, spurs, or dikes vary with the nature of the country in which they are situated. It is always a very difficult operation to close any waterway, especially when the bed is easily removed. If the dam be executed by commencing from the two sides, the passage becomes contracted, the speed of the current augments, and necessarily the bed becomes deepened. If, on the contrary, the dam be executed in horizontal layers, the waters retained flow over the top and produce a cascade which is likely to overthrow the structure. It appears, however, preferable to adopt this latter course, wherever it is feasible. In any case it is requisite to execute these works at seasons of the year when the waters are lowest.

Whatever system be adopted for such river-works, it is indispensably necessary that any defect be remedied at once. Constant inspection, great care, and continual labour are the only means by which the banks of rivers can be maintained. No short-sighted notions of economy should be allowed to interfere with the organisation of an efficient system of maintenance.

Dams or Barrages in Rivers.

50. When rivers bring down small volumes of water, the simplest method of rendering them navigable is by the erection of dams or barrages across their beds, thus creating a series of ponds. The communication between these ponds may be effected by sluices, as before observed in the case of floatable rivers, or by locks, or even through a pass left constantly open. These last are, however, simply transverse jetties, which narrow the bed of the river.

Dams may be either fixed in their whole height, or they may be movable in such a manner as to leave a free passage for the waters in time of floods.

Formulæ of Flow of Water.

The object of continuous dams is to cause the waters to rise on their up-side, so as to obtain a sufficient depth for the purposes of the navigation. Their result is to diminish the depth of the waters below, in consequence of the additional velocity acquired by the fall over the crown of the dam. The depth of water upon the crown depends upon the length of the dam. M. Castel's formula for ascertaining it (which is generally adopted by Engineers in calculations of this nature) is

$$x = 0{\cdot}64 \sqrt[3]{\left(\frac{Q}{L}\right)^2},$$

in which x is the height sought; Q, the discharge per second; and L, the length of the dike or bank.

51. Although the dam produces the effect of retarding or heaping up the waters, it is not immediately upon it that they attain the greatest depth, but at a certain distance above. The surface of the fluid assumes a convex form before arriving at the dam, the curve of which commences at a very considerable distance. MM. Guilhem and D'Aubuisson consider the curve to be a portion of a hyperbola whose summit is above the dam before the waters begin to fall, and whose asymptote is the line of the natural mean fall of the waters before the establishment of the dam. The equation of this curve would be

$$\left(\frac{y + p\,x}{\mathrm{H}}\right)^3 - \frac{p\,x}{\mathrm{H}} = \frac{1}{1 + \frac{4}{g}\,\mathrm{H}\,\frac{(p\,x)^6}{\mathrm{H}}},$$

in which x is the horizontal distance of any point in the curve to the dam; y is the height to which the waters are heaped up at that point above the original level; H, the greatest height to which they are raised; p, the fall of the bed of the river, in this case supposed to be straight.

It is usual to place the dams at sufficient distances from one another to allow the level of the waters thus kept back to meet the level resulting from the natural fall of the bed. The crown is kept at about from 8 inches to 1 foot below the height calculated for the augmented depth. The formula for calculating more exactly the distance of the extreme point of the difference of level created by the dam is (supposing the coefficient of contraction to be 0·70)

$$q = 1{\cdot}86\,l\,d\,\sqrt{d + 0{\cdot}08\,\mathrm{V}^2},$$

in which q is the quantity of water discharged per second; l, the width of the dam; d, the distance of the extreme point sought; V, the mean velocity of the up-stream. M. D'Aubuisson prefers the formula

$$q = m\,\tfrac{2}{3}\,\sqrt{2\,g}\,.\,l\,h\,\sqrt{h},$$

in which m is the coefficient of contraction; h, the difference of height between the crown of the dam and the sheet of nearly stagnant water which is found above it.

Different Systems of Dams.

52. There are two methods of establishing dams in rivers; either with small falls often repeated, or at considerable distances asunder with great falls. The latter system has the advantage of causing less interruption to the navigation, and of losing less time in the passage of the locks; but it is accompanied by great increase in the expense; for as the weight of water acting upon any construction increases in the ratio of the squares of its height, the strength and consequently the expense of the works must increase in the same ratio. The height usually adopted for river locks is rarely above 6 feet 6 inches: when there are no locks for the passage of the boats, the height is not more than from 3 feet 3 inches to 4 feet 3 inches. The nature of the bed of a river also becomes an important element in the solution of the question as to the position of the dams. It is evidently essential that they should be placed in positions where the fall of the cataract is not likely to undermine them.

In order to augment the width of the section, and thus to diminish the velocity of the stream falling over a dam, it is frequently made with an inclination towards the stream. But as the direction of the water flowing over is always normal to the line of the crown of the dam, it is likely to produce corrosions upon the banks on the down-side. A safer way of augmenting the section is to dispose the dam in a convex form to the up-stream; or, if the labour upon the masonry of this arched shape be too great, a *chevron brisé* may be substituted, observing that the salient angle is presented to the stream. Both of these forms have, however, the disadvantage of con-

tracting the waterway, and of facilitating the deposition of silt in the angles of junction with the locks or sluices.

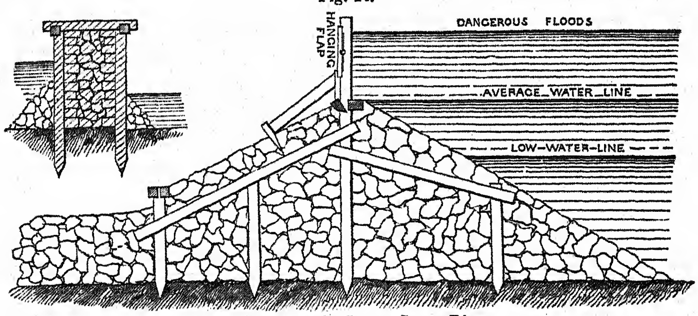
Construction of Dams.

53. Dams are made either with vertical faces or with slopes. The vertical face presents the advantage of immediately checking the velocity of the current by the effects of the cataract; but in this case other works are necessary, to secure the foundation. If the down-side be made with a slope, the excavating action of the water is diminished, but the mass of the construction is augmented. Local considerations of economy must guide the Engineer in the choice of the form to be adopted; the nature of the bed also forms a very important object of consideration in the determination of such questions.

An example of the mode of constructing the dams used in the United States is given in figure 22, page 278. In this case they were made in sections about 20 feet long, as in the example given, of timbers 20 inches square, notched down upon one another 3 inches. These sections were gradually sunk into their positions, well fastened together, loaded and backed up with stones and gravel. Six-inch planking is laid on the upper surfaces. This dam has an inclination of 45° to the stream, and measures 72 feet across at the foot. The total length is 1600 feet. A portion of it is executed in rubble, for a length of 270 feet, the width at the top being 12 feet, and at the bottom 150 feet.

Dams are sometimes executed in vertical cases of wood-work, similar to coffer-dams, and consisting of main and sheet piling, filled in with rubble, the foot of the down-side being protected by loose stone left to find its natural slope. Again, at other times an open frame-work of carpentry is driven into the ground, which is filled in also with rubble, but dressed off to a regular slope, which is much greater on the down than on the up-side.

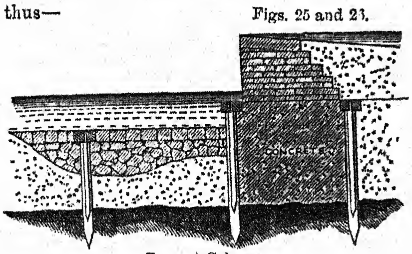
Fig. 24.



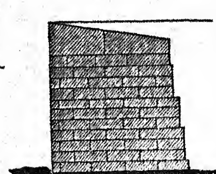
Stone Dam on the Lesser Saone River.

54. The crown of a dam must always be made with an inclination towards the up-stream, in order to facilitate the afflux of the sheets of the fluid towards the extreme edge, thus—

Figs. 25 and 26.



Dam at Coly.



Dam upon the Blavet.

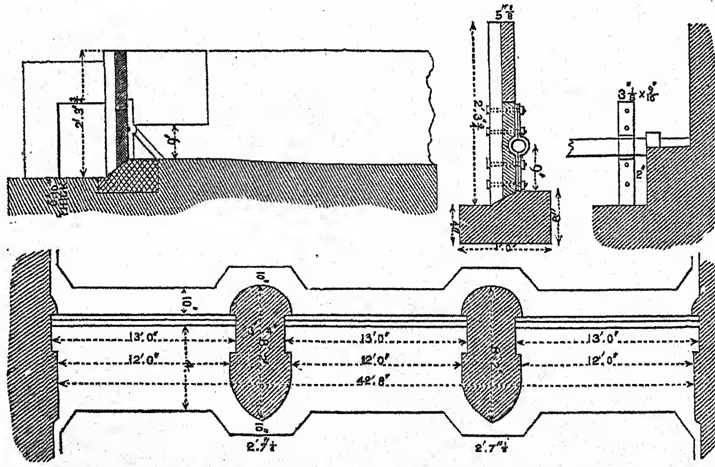
Another very necessary precaution to be observed in constructing the dams of timber-work is to prevent any of the beams from traversing the whole structure, as they would in that case act as pipes to allow the water to pass through.

The platform on the down-side should be made of a length equal to three times the height of the dam, when the latter is vertical. It is advisable to strengthen the part upon which the water falls directly, and, if possible, to interpose some elastic substance, such for instance as a bed of fascines. The lower extremity of the platform must be guarded by a range of close piling.

In some rivers the dams are made with openings, to which gates, or other methods of closing, are applied ; so that they are shut during the dry seasons, and open when the waters rise. These dams present a series of piers and openings in the river precisely analogous to the piers of bridges, and they require the same methods of construction and defence those works would. The dimension of the openings is regulated by the mode of closing, and it varies from 13 to 26, or even to 48 feet, according to the size of the boats or the violence of the floods.

55. On the Marne, the Yonne, and the Aude, the system of closing consists in a set of movable blades turning on a pivot at the bottom, and bearing against a bar at the top, which itself is movable. A bolt being drawn, the weight of the water forces the top bar to swing round, and the blades then fall to the bottom, leaving the pass clear. In other cases the blades are horizontal, and shut against a vertical locking-bar, or the blades are converted into a solid door or gate. When the openings are not intended for the purposes of navigation, they are closed by vanes set in motion by crabs or winches, or by horizontal flaps at different heights. Sally-gates have been used, but they require too great an effort to open them against the stream. Turning-gates upon vertical hinges have also been tried, but they are objectionable, in the first place, because they hinder the navigation; and in the second, because they require an extra thickness of very expensive masonry. In cases where the height of the water kept back has been but insignificant, it has been found that the use of dams which open and shut simply by the weight of the water acting upon them has

Fig. 27.



Self-acting Dam at Pont de la Pradès, at Riom.

answered tolerably well. Their application is, however, very limited, because when

the height becomes important, the construction of these works becomes proportionally complicated and expensive; they are also liable to be easily put out of order, and are difficult to repair.

The width of the sluices left for the flood-waters or fo: floating the wood-rafts, upon the Continent, varies from 10 to 26 feet. In order to economise time, and, to a certain extent, the works necessary to the efficient service of these sluices, it is generally found to be advantageous to place them at one of the extremities of the dam. When locks are constructed, the sluices are placed close to them for the same reasons. The floor of the pass of the sluice is kept at the same level as the bed of the upper portion of the river, and is joined by a regular fall with that of the lower, so that in case of necessity, the sluice may be used for the passage of boats. When the bed of the river is soft, the floor of the sluice must be protected by a platform.

The dam indicated in p. 281, as being used upon the Lesser Saone, is a mixed construction, one part being fixed, the other movable. The fixed part varies in height rom 2 feet to 4 feet above the low waters; the movable parts, which consist of a series of leaves turning upon horizontal pivots, vary in height from 1 foot 4 inches to 4 feet 6 inches. When the floods attain a dangerous degree of elevation, they overbalance the movable parts, which fall flat, and thus allow the surplus water to escape.

Movable Dams.

56. M. Poirée, Engineer in Chief of the navigation of the Seine, introduced upon the Yonne, and subsequently upon the Seine itself, a kind of movable dam whose application is spreading very rapidly in France. It consists in the use of a series of metal frames, fastened together at the top, so as to be laid flat on the bed of the river by turning on their bases as hinges. The frames are let into a groove sunk in the floor of the dam, in such a manner that the frames, when laid flat, do not project above the bed of the stream. The frames are maintained in their vertical position by a movable bar which fits down upon them, and serves to keep the blades closing the waterway in their positions at the top. At the bottom, the blades fit into a groove made in the floor of the passage. They are of wood, from 4 to 5 inches wide, and are pressed against the top bar by the weight of the water. The height of the frames may vary from 4 to 10 feet; their distance apart is made equal to their height, with a small allowance for play. These dams are exceedingly economical, and they present the advantage of being susceptible of leaving the whole or any portion of the water clear, as occasion may require, whilst they are equally effective in closing it entirely. M. Poirée estimated the expense of such dams at about £40 per yard run.

57. Whatever be the nature of the dam employed, some means are required to enable the navigation to pass from one level to the other. For floatable rivers, sluices suffice, which must be made of such dimensions as to be able to pass any raft of the ordinary construction of the country. The wing-walls of the passage must be continued down the stream, to guide the boats, and more particularly to diminish the curvilinear fall of the water. The danger attending the difference of level above and below the dam induces Engineers in practice to recommend that the sluices be opened about a quarter of an hour before boats or rafts are to be passed, although, by so doing, the level of the water in the upper bay is inconveniently depressed. For the facility of guiding boats through the sluices, it is desirable that they be placed as near the towing-path as possible.

Locks for River Navigation.

Locks, &c., for Rivers.

58. The use of sluices is accompanied with so much danger and difficulty, that in all cases where the navigation assumes any importance, locks are substituted for

them. Locks may be called hydraulic machines, by means of which heavy cumbrous bodies are raised from one level to another, or *vice versâ*. They consist of a basin of variable surface, which is closed by gates at each end. The floor of the lock is on a level with the bed of the lower part of the river to be communicated with. The crown is slightly above the upper surface of the water. When a boat is to be passed from the one to the other, it then becomes necessary to alter the level of the water in the intermediate basin, so as to bring it to that of the respective bays. The boats are thus passed from one to the other without the risk of shocks, and with the least possible expense of water.

59. River locks may be placed in the bed of a river, or in a short branch made parallel to the main bank. When a river divides into several branches naturally, it

Fig. 28.

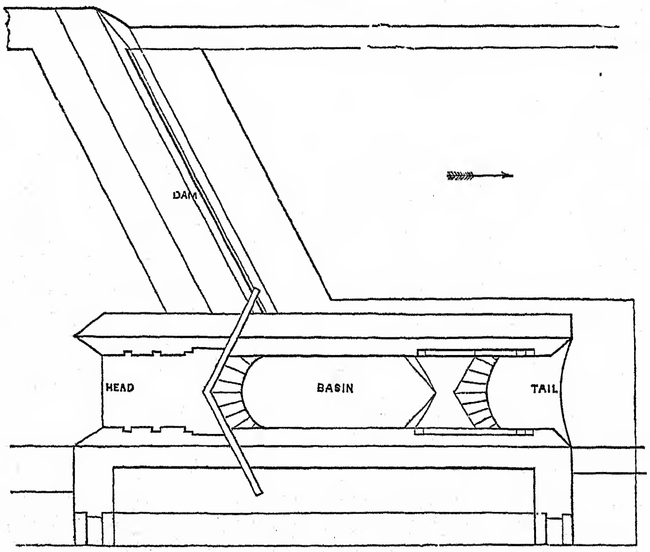
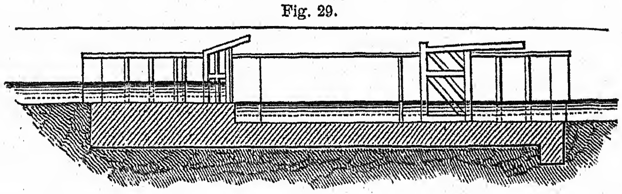


Fig. 29.



is usual to place the dam at the head of one of them and the lock at the end of the other, so that the intermediate portion of the original bed of the river becomes converted into a basin. The reasons for which this particular arrangement is adopted are, because it is easier to construct the lock in such positions, by merely diverting the waters of the river in the mean time into the secondary branch; and because the still water thus created above and below the locks, free from the agitation of the cascade over the dam, is found to be highly advantageous to the navigation. Moreover, the lock itself in such positions is less likely to be affected by gravel or mud, especially if guard-gates are placed at the entry of the basin thus formed.

If, however, the form of the river be such as to render it indispensable to place the lock in the bed, it must be placed at one extremity of the dam, so that the side wall forms also the retaining wall of the towing-path. The tail-walls must be prolonged into the stream, so as to remove the boats from the agitation produced by the waters falling over the dam; and by this disposition the wing-walls, upon a considerable portion of their length, are removed from the charge of the water in the upper level or pond.

60. A very important question to be decided in the construction of river locks is whether they should be submersible or not. In the former case, great danger is incurred from the effects of the waters acting upon the embankments by the side of the wing-walls; and it is necessary, in order to guard against this danger, that they be covered with a stone paving laid on a bed of concrete. The gates should also be opened in order to prevent any kind of cataract. Where the locks are kept entirely out of the water, they offer the serious impediment to the navigation of requiring that the towing-paths be elevated, sometimes to a very inconvenient degree; and they also require long inclines to reach the level part of the embankments. It may be said, however, that when floods attain any degree of elevation, such as to render it necessary to keep the top of the locks inconveniently high, the navigation is entirely suspended: all the advantages are therefore in favour of submersible locks for river navigation.

If the locks be insubmersible, it is desirable, to facilitate the working in ordinary states of the river, that the tail-gate especially be made in two parts; the upper part to shut against a rabbet in the lower one.

With the exception of these cases, the locks are closed with double sally-gates, the difference of level of water being obviated by means of vanes, or water-ducts, as explained in the following Section on Canals. It is advisable in all such works to leave grooves in the wing-walls to receive a temporary dam, in case repairs are found necessary.

The same perfection is not required for a river lock which is found necessary for canals, as they are hardly ever liable to be short of water. Still there is so important a loss of time resulting from the infiltration through the wing-walls, that it has been found to be advisable to have them well built. The same motive of economy of time has led in some cases to the placing of a supplementary pair of gates, in order that when small boats have to pass the lock, it may not be required to fill the whole length of the basin. When the navigation is very active, it may occasionally be necessary to make more than one lock: in that case it would be better to make them side by side, as the middle wing-wall would serve for the two. At all times it is necessary to pay particular attention to the size of the boats frequenting the river or its affluents, for that must regulate the dimensions of the locks.

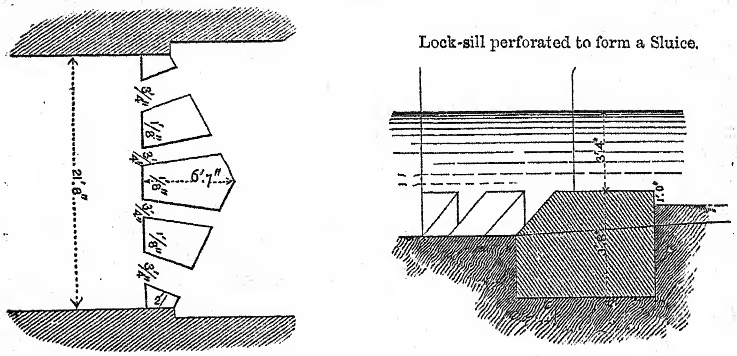
61. It has occasionally been found advisable to establish sluices in the lock-gates, for the purpose of scouring out the mud, especially in river locks. The action of these sluices is, however, very imperfect when the cascade-wall is high enough to prevent the water from sweeping the bottom of the basin. This inconvenience has been remedied in some cases by making the bottom line in a regular incline from the entry of the lock to the tail-gate. In the United States, the cascade-wall is often thus suppressed, and in the middle of the basin a grating is fixed, to catch any aquatic plants likely to interfere with the opening of the lower gates. On the Loire an intermediate system has been followed, by which the height of the cascade-wall has been diminished without being entirely suppressed: in fact, it has been found that the extra height thus given to the upper gates rendered their action slow and difficult.

62. Great precautions are indispensably necessary as regards the foundations of

river locks, to protect them from the extreme force of the excavating powers of the stream. Even when the bed of the river is of a resisting character, it is advisable to let the foundations into the rock about 3 or 4 feet. If the bed be likely to yield, a long platform must be executed both above and below the lock, so as to form there at least a solid bed. If the work be upon piles, the extremities must be protected by a continuous range of close piling, and any projecting part beyond the line of the first set-off must be carefully paved. In making a floor it must be borne in mind that the weight of the water of the upper level acts upon it to blow it up; the

Fig. 30.

Lock-sill perforated to form a Sluice.



dimensions must therefore be sufficient to resist this action. It is always preferable to execute the floor as an invert.

In the United States many inclined planes have been executed to carry vessels over considerable falls. Indeed the difficulties attending the establishment of locks in rivers are so great, that they have led Engineers to prefer the construction of lateral canals, whose works, especially in the intermediate portions, are much more easy of execution, and also much less exposed to accidents from floods. Details of the execution of lock-gates and the other parts of such constructions will be found in the succeeding pages.

SECTION II.—CANALS.

1. The dangers alluded to in the first portion of this article as attendant upon the construction of works in the bed of rivers, and the constant interruption to which the navigation is exposed from the various conditions of their course, sufficiently explain the preference accorded to lateral canals. These canals, however, only serve to regulate the navigation in the direction and, generally speaking, in the hydrographical basin of the existing streams. Another very important class of canals is the one designed for the purpose of forming a navigable communication between rivers flowing perhaps in opposite directions, and to overcome the difficulties arising from the interposition of the mountain chains whence the rivers take their source. Such canals, then, have forcedly a summit-level, and lock down in both directions, in order to carry the navigation over the differences of level.

From these circumstances canals may be separated into the two main divisions of lateral canals, and canals with a summit-level.

Lateral Canals.

2. *Lateral Canals.*—This first category comprises all derivations from rivers which are made either for the purposes of navigation, for irrigation, or for the supply of the water-courses of mills and factories. They may be made with a slight fall, so as to

maintain a definite velocity in the water, or they may be made so that the respective portions between the locks assume the character of pools of stagnant water, without any perceptible flow. The former arrangement is applicable in cases where the navigation only takes place in the downward direction, or where the motive power of the water is to be made use of. An instance of a canal with a constant fall is to be found in the Canal de l'Ourc, near Paris. Upon it the navigation only takes place towards the capital, and the derivation itself serves also to carry the water to the town, for the public fountains, washing the streets, &c., and likewise to furnish the water requisite for the canal which runs round the north side of Paris.

Movement of Water.

The formulæ which express the conditions of the movement of waters in a canal whose section is constant and fall uniform, are usually given thus:

$$Q = S\,v\,;\ \text{from which equation,}\ v = \frac{Q}{S};$$

Q being the volume discharged per second; S, the section of the stream; v, the mean velocity per second. Or, M. de Prony gives another formula:

$$V = u\,l\,h\,.\ u = -\,0{\cdot}07 \pm \sqrt{0{\cdot}005 + 323\frac{i\,l\,h}{l+h}};$$

in which l is the mean width; h, the depth; i, the fall; u, the mean velocity per second. Of course it is to be observed that in all the formulæ used by the French Engineers, they have exclusively employed the metrical system.

3. In all canals where it is desired that the waters should have a definite flow, it is indispensable that the fall be maintained uniformly throughout its length. On the Canal de l'Ourc, the Engineer, misled by his theoretical reasoning upon the shape assumed by the longitudinal profiles of rivers, adopted the plan of making the bed of the canal a species of catenarian curve. Upon this principle the fall in one part was made $0^{m}{\cdot}0000625$ per mètre, in the other $0^{m}{\cdot}0001236$ per mètre, instead of being a uniform fall throughout its whole length. The result was, that the flow over the highly inclined portions became rapid and the depth feeble, whilst in the more level parts the flow could hardly be said to exist, and there was an excess of water.

An important observation made by Dubuat on canals of this description, was to the effect that the aquatic plants retard the flow of the water to such an extent as almost to require that the inclination be double that indicated by theory.

4. It is usual to make all lateral canals, and even in many cases summit-level canals, with falls such as we are now considering, in order to compensate for the loss of water which takes place from evaporation, lockage, or infiltration. The direction of the movement of the navigation does not affect the rate of fall so much as the consideration of the stability of the works, although doubtlessly it is a very important element in the solution of the question. Practically, a fall which would produce a velocity of so much as 1 foot per second may be taken as the extreme limit for a canal navigable in both directions: 1 in 20,000 is, however, sufficient to produce a flow sufficient to compensate for the causes of loss above mentioned. The excess of water thus admitted into the respective ponds should be diverted round the locks by a culvert, rather than be allowed to flow over.

The works connected with lateral canals, which differ the most from similar works upon summit-level canals, are those by which they communicate with the upper or lower parts of the river; those by which they occasionally pass from one bank to the other; and those by which they communicate with the sea, for nearly all the ship-canals may be classed amongst those now called lateral.

5. The communications with the natural bed of the river are of the most serious

importance, for upon them depends the attainment of the facilities requisite for the management of the boats. The security of the latter from floods, the necessity of always commanding a sufficient depth of water, the importance of keeping the entry clear of the silt of the river,—all combine to complicate the difficulties and to increase the importance of this part of the work.

Upper Junction. A careful examination of the most successful works of this kind leads to the conclusion, that the best principle to be followed in their execution is to place them at a rather acute angle with the natural flow of the river, the immediate junction being effected either by a large basin or by means of a curve. Under all circumstances, it is necessary to have a basin at the point of junction, on account of the differences of level the rivers are constantly exposed to from floods or tides.

If, at the point where the upper junction is established, there be not sufficient depth of water at the low summer-level, it is necessary to make a dam. If the river, however, be one which brings down much gravel or silt, depositions are likely to take place, which would render such works useless. The silting up of the bottom of the basin is only to be obviated by dredging, or by establishing powerful sluices to scour out the portions necessary for the navigation.

The feeders must be removed from the influence of floods; firstly, in order to avoid the dangerous effects of the cascades they might produce; and, secondly, to avoid the silting up of the canal by the muddy waters they bring down. The gates at the entrance are often made in separate portions when it is necessary to give them a great height, in order to attain the object of shutting out the floods. Sometimes the first basin of the lateral canal is so arranged that its level may be alternately above or below that of the river. In this case a double set of gates is necessary.

Outfall. 6. The outfall, or bottom junction with the river, may be either directly in the stream itself, or in waters which communicate with it. The latter course is taken when there is danger of silting up, or of the formation of natural bars by the deposits of alluvium from the river. However the canal may communicate with the river or sea, it is necessary that the junction take place in such a manner as to facilitate the passage of boats from one to the other; that there be at all times a sufficient depth of water; that it be possible, should occasion arise, to establish sluices, as at the upper or feeder junction; and that the last basin be of sufficient dimensions to receive all the vessels which might require to lie there. This last basin also should, if possible, be without locks towards the upper part of the canal, and only be closed towards the river. On any lateral canal where there is an important and active navigation, such basins or docks are of the highest utility, both for the safety of the boats, and for the facility of commerce. On the lateral canal of the Mississippi, and that of Pont Chatrain, in a length of about five miles it was proposed to make no less than fourteen basins, besides three docks,—two at the entry and one at the outfall. At the outfall the same difficulty is met with, from the variations in the height of the river-water at the upper junction. But as the outfalls are usually in the tidal parts of the river, it is more necessary to render them constantly insubmersible than it is in the latter case. (See the plans of the upper junction of the lateral canal of the Rhône at Beaucaire, of the passage of the lateral canal of the Loire from one side of the river to the other, and of the junction with the Medway of the former Thames and Medway Canal.)

The communications between lateral canals and tidal waters are necessarily more complicated than those in ordinary rivers, from the great differences of level met with in the former. It is usual to take as the lowest point of such locks the levels of the mean neap-tides at low water. Such a course saves time in passing through the

locks when once open; but boats are forced to wait at least six hours between tides, and the last basin is liable to be soon silted up.

Dimensions of Locks.

7. The question of the dimensions to be given to the locks is more simple in the case of lateral canals than in those of an ordinary character, for they are always certain to have an ample supply of water. They may then be made so large as to receive two or more boats at a time in the intermediate basin. It is questionable, however, whether the delay in the operation of filling the basin does not more than counterbalance the advantage of passing simultaneously several boats. At the outfall this consideration may be overruled by the facilities large locks offer for the entry of even sea-going vessels into the docks or basins.

Direction.

8. As far as it is possible, lateral canals are established in the valley in which the river itself runs, in order to avoid any extreme differences of level likely to require the execution of deep cuttings or tunnels, and also in order to have close at hand the means of supplying any loss of water. Sometimes, to effect this object, it is necessary to embank a portion of the bed of the river itself, as the hills often terminate abruptly in steep bluffs, washed at the foot by the stream. Such a case is met with in the lateral canal of the Tenessee, in the United States. When the floods of such rivers are of a moderate range, it is desirable to make the dams which separate the canal from them of a height sufficient to prevent their being overflowed; otherwise the works must be executed in such a manner as to resist the action of the water upon them, and facilities must be provided for the cleansing of the bed.

Meeting with Affluents.

9. Necessarily in following the valleys of the main stream, lateral canals meet with all the affluents which fall into it; and these often give rise to serious difficulties. It is easy, of course, to pass small rills through culverts; but as these serve to carry off the natural drainage of the secondary valleys, they are in their turn exposed to floods. Their free discharge in all conditions is therefore one of the first and most important means of insuring the stability of the canal. Sometimes also a variation in the physical and geological character of the country may render it advisable to change the position of the canal from one bank to the other, thus adding to difficulties met with in traversing an affluent. This is sometimes, as in the lateral canal of the Loire, effected by making the passage across the river at the natural level of the latter, and consequently exposed to all its irregularities; or by means of an aqueduct-bridge, which may produce very serious inconvenience by damming up the floods.

Canals with a Summit-Level.

10. Artificial navigable canals may be regarded as roads upon which the transport is effected in still water, so as to allow communication between two valleys having their own natural navigation, without forcing the boats to be unloaded. The objects to be attained in their execution are,—firstly, that their total length be the least possible; secondly, that the difference of level in the intermediate distances be as small, and the number of locks as few, as is consistent with a due regard to economy. The evaporation, the loss of water from filtrations, and the passage of boats through the locks, render necessary the execution of important works to insure an efficient supply of water. It often happens that this necessity leads into considerable expense, and causes a prolongation of the course of the canal.

It has been already observed, that the economical conditions of traction upon a canal are, that up to a speed of 3 feet 4 inches per second, the power, whether of men or of animals, is sixty times more effective upon a canal than upon a good road; and it is about five or six times as efficient as upon a level railway. The ratio of the power diminishes very rapidly as the speed of movement through the water increases,

at least up to a velocity of from 10 to 13 feet per second. We may then assert that, at least with the present form of canal-boats, canals are only adapted for the conveyance of heavy cumbrous articles which do not require a high speed. It is also to be borne in mind that the passage from one lock-level to another (an operation in all cases of from fifteen to twenty minutes' duration) adds materially to the length of time occupied in the transit.

The remarkable researches upon the movement of boats at high speeds in canals, begun by Messrs. Grahame and Fairbairn, and so skilfully continued by Mr. Scott Russell, have, as was before said, thrown a fresh light upon the subject of the resistance of water to the movement of boats. The laws which appear to regulate its action may be given in the words of the Report of the British Association for the Advancement of Science, as follows :

"The resistance of a fluid to the motion of a floating body will rapidly increase as the velocity of the body rises towards the velocity of the wave of displacement caused by the said motion, and it will be greatest when the two velocities approach equality.

"When the velocity of the body is rendered greater than that due to the wave, the motion of the body is greatly facilitated. It remains poised on the summit of the wave, in a position which may be one of stable equilibrium ; and this effect is such that at a velocity of 9 miles per hour the resistance is less than at a velocity of 6 miles per hour behind the wave.

"The velocity of the wave is independent of the width of the fluid, and varies with the square root of its depth.

"It is established that in every navigable stream there is a velocity at which it will be more easy to ascend against the current than to descend with the current. Thus, if the current flows at the rate of 1 mile per hour in a stream 4 feet deep, it will be easier to ascend with a velocity of 8 miles per hour on the wave than to descend with the same velocity behind the wave.

"The velocity of the wave of displacement is about 8 miles per hour."

It is unfortunate that the economical results of the application of the ingenious researches which led to the ascertaining the above interesting facts should not have succeeded.

11. At the present day the rage for railways has caused canal navigation to be somewhat neglected. A more efficient system of working them, a rectification of their course in some cases, and an improvement in the forms of the boats to be employed, would enable the public still to derive extensive benefit from a class of constructions far too much neglected at present. One vital error in the management of canals has lien in the admission of private persons to the right of running boats upon them. In the hands of Companies able to pay for, and whose interest it would be to make experiments to ascertain the possible improvements to be introduced (either in the mode of traction or the form of boats), it is nearly certain that the present system would very soon be superseded. As it is, even the heavy traffic is leaving the canals, in spite of the disproportion of the exercise of power necessary to carry it upon railways.

The elements which enter into the constitution of the price of carriage upon canals shew, indeed, how in various ways the present organization of their traffic acts unfavourably upon their beneficial results. These elements are—

1st. The cost of loading and unloading, which can never be so economically done on a small as upon a large scale.

2ndly. The cost of transit, including the first cost and the subsequent wear and tear of boats and horses, and the expenses of the crews.

3rdly. The tolls, or the payment necessary to cover the interest upon the capital employed in the original construction of the canal, and the annual sums expended for its maintenance.

4thly. Any government tax, insurance, risk, &c.

Now all these elements would be susceptible of diminution, if the whole traffic were concentrated in the hands of the Companies. The public would also gain by such a course, for it would enable canals to compete more favourably with railways, and thus to break down the monopoly the latter are arriving at.

Some canals with a summit-level are so situated that the fall is entirely in one direction, as, for instance, most of the canals in Belgium, and that from Arles to Bouc. The remainder have falls on both sides from the summit, and they thus traverse the mountain chains which divide the respective valleys between their points of arrival and departure. Such are the Canal of Languedoc, (the first work of the kind executed in Europe,) and the greater number of the canals executed in France, England, Germany, and the United States. The first description may be considered as constituting canals with only one branch ; the second are canals with a basin at the summit-level, and branches descending from it on both sides.

Choice of Direction.

12. When it is desired to construct a canal between any two particular points, it is advisable first to examine with great care the nature of the intermediate country, and to ascertain whether there be any points, even within a tolerably wide range, whose natural productions are of sufficient value to require a deviation in the course of the canal to insure their passage over it. The situation of all the mines, quarries, important factories, or large centres of consumption, must be noted, as upon them the advantageous results of the undertaking will mainly depend. Trial levels and cross-sections of the country through the different routes which appear suitable, must be taken, to ascertain the nature and quantity of work to be executed, whether of cutting, tunnel, or embankment. The various springs and water-courses must be noted, and the actual uses to which they are applied carefully considered. In densely peopled and highly civilized countries, like our own, we often find indeed that more difficulty and expense arise from interference with the waters of ornamental gardens, than from streams more usefully employed. In new countries and the colonies, the use of water privileges complicates the questions connected with the diversion of, or interference with, streams. The main object being, however, to put the two extreme points in communication, it is essential that the route chosen be as short as possible, without losing sight of any collateral traffic, or incurring needless expense.

Summit-Level.

13. In case the country to be traversed should be of a very irregular nature, one of the most important questions to be solved is the position of the summit-level. This must be placed as low as possible, for the double reason of obviating the necessity for many locks, and in order to insure the most perfect supply of water.

Occasionally, but very rarely, the point most fitted for the summit-level is found to be the position occupied by a lake or pond of sufficient importance to supply the lower portions of the canal. The pond of Longpendu is an instance of this remarkable geological formation. It pours its waters into the Loire on one side, by a little river called the Bourbince, and into the Saone, on the other, by the Heune. The pond of Cony is also in an analogous position, for it communicates on the one side with the Moselle, by the Niche, and on the other with the Saone. Such natural indications of the route are, however, quite exceptional, and it much more often happens that the central ridge of the chain to be passed is obliged to be traversed in tunnel.

More than ordinary care must be taken to ascertain exactly the sources of supply of

water to the summit-level, and to proportion it exactly to the wants of the navigation. All the streams which can be brought into it must be carefully gauged in every state of the temperature or of the year, and the geological constitution of the neighbouring country examined, to ascertain whether it be possible to secure a supply of water from wells. The quantity of water to be furnished by the summit-level must depend upon the length of canal to be fed by it,—the length, breadth, and height of the locks,—and the number of boats to be passed in both directions. In case the probable supply of water be exposed to occasional interruptions, or be deficient in quantity, it may be advisable to substitute inclined planes for locks, or it may be necessary to follow the system employed on some of the American canals, of substituting a railway for a considerable distance.

In the branches from the summit-level it is desirable that as long reaches of level canal as possible should be constructed, to admit of the concentration of locks. On some canals, where two or more locks have been constructed close to one another, the Companies have placed a man specially charged to keep them in order; and where they have been detached, the damage done to the locks has often forced them to erect a lock-house for the service of a single one.

Dimensions of Canals.

14. The dimensions to be given to a canal require also very mature consideration, especially when the total development of the inland navigation is considerable. In all countries but England, the tendency of the river navigation is to employ a larger and deeper kind of boat than was employed before the works for the improvement of rivers were effected. Our own large tidal rivers, however, as was said before, place us in an entirely exceptionable position. Sea-going vessels come so far inland that it is not necessary to send our canal-boats to sea. Our mode of working canals also renders it preferable to use a boat able to be drawn at a small expense and worked with few hands. Mr. Chapman observes that "the system of small canals is peculiarly eligible for countries where limestone, coal, iron ore, lead, and other ponderous articles not liable to damage from being wet, or likely to be stolen, are the chief objects to be attended to; and where the declivity of the country runs transversely to the course of the canal, which will generally be the case along the sides of mountains, at an elevation above the irregular ground at their feet." But we must not forget that both theoretically and practically the conditions of movement through a small canal are less advantageous than when it takes place through a wide one. The section of the boat in the former bears a greater proportion to the water section than in the latter, even when small boats are used. The resistance of the water is consequently greater.

On the Rhône, the barges in use carry 75 tons; on the lower Seine, between Paris and Havre, they are, as already mentioned, sometimes as much as from 500 to 600 tons burthen; on the Meuse, barges are employed of 250 tons burthen, drawing 4 feet of water. The steamers which navigate those parts of the Tenessee formed by canals are of 120 tons burthen, with a draught of water of 5 feet. The limits of the size of the boats are not finally determined; and the inference to be drawn from the above facts is, that in the future development of commerce it is desirable to make a canal as wide as possible, in accordance with motives of economy and the supply of water.

On some of the French canals the width was settled without any reference to the dimension of the boats frequenting the rivers thus put into communication. The consequence was that goods were necessarily transhipped at both ends of the canal at an enormous expense. The Administration of Public Works in that country, to avoid a recurrence of this blunder, have adopted, since the year 1822, the following dimensions:

Canals for 'grande navigation' are made 33 feet 4 inches wide upon the floor-line, and 49 feet 6 inches upon the water-line, by 5 feet 5 inches depth of water. The locks are 106 feet 8 inches long by about 17 feet wide; the towing-paths 13 feet wide.

Canals for 'petite navigation' are made only 33 feet 4 inches wide upon the water-line, and 22 feet on the floor, with a depth of water of 5 feet. The locks are 100 feet long by 9 feet 1 inch wide. The Canal de Berri is of this class.

Some of the French canals for steam navigation have locks from 26 to 40 feet wide, and of lengths between 150 and 233 feet in clear of the gates.

In England, no very definite rule appears to have been followed in fixing the dimensions of canals. Those executed for the important internal lines vary from 31 to 48 feet upon the water-line, with an average depth of above 5 feet. The locks are generally 70 feet in length by from 14 feet 6 inches to 18 feet wide. Small canals, in the mining districts, have in some cases been executed with a width of not more than 16 feet upon the water-line, and they range from that to 28 feet. The locks are made of the same length as for large canals, but of only half the width.

Ship canals have been made of much larger dimensions, such, for instance, as the Caledonian Canal, which has in parts 122 feet upon the water-line, with a depth of 20 feet. The Gloucester and Berkeley Canal has a water-line of 70 feet, and a depth of 18 feet. The Thames and Medway had a width of 50 feet by a depth of 7 feet; the Ulverstone, 65 feet by 15 feet; the locks, of course, being in proportion to the size of the canals.

In the United States, the same irregularity occurs in the dimensions of canals as in our own country. Two extreme cases of ordinary works may be cited, in the Erie and the Morris canals. The first is 70 feet wide on the water-line by 7 feet deep; the second is 32 feet wide by 4 feet. The lateral canal of the St. Lawrence is in some parts as much as 150 feet wide, and occasionally as much as 10 feet deep. All such ship canals are, however, executed in situations where an unlimited supply of water is to be found.

Supply of Water.

15. The dimensions of the canal being once settled, it becomes necessary to determine the positions and dimensions of the reservoirs and feeders. The consumption of water arises from several causes; some of which are regulated by the activity of the traffic,—some of them are independent of it.

The causes of loss, independent of the navigation, are—firstly, the evaporation; secondly, the filtration; thirdly, the escape through the defective parts of locks or other works; and fourthly, the loss occasioned by filling the whole canal after the waters have been let out for the purpose of repairs.

The causes of consumption of water, dependent upon the navigation, are—the loss occasioned by lockage, and the quantities of water it is often necessary to bring down from the upper levels to compensate for the deficiencies caused by the too sudden affluence of boats to the lower ones.

Evaporation.

16. The loss of water by evaporation is greater in proportion to the surface exposed and the nature of the canal. It varies with every position, and, in the same country, with the seasons, according to the different hygrometric states of the air, the prevailing winds, and the extremes of heat or cold. The quantity of rain which falls upon, or may run into, the canal, must be deducted,—but these are very variable. In warm latitudes showers are rare, and although they are sometimes excessive, they are of little importance as far as they affect the supply of a canal, which requires, above all things, an uniformity of level upon its water-line. In the temperate latitudes of Europe, the mean fall of rain may be taken at 2 feet per annum, and the evaporation at from 4 to 5 feet, in districts through which canals usually pass. The daily loss

under such circumstances is, then, about from $\frac{1}{16}$ to $\frac{1}{12}$ of an inch per day, on the average. In the summer, however, the evaporation is great without any compensation, and in such periods it may be necessary even to calculate upon a loss of not less than 4 inches in the twenty-four hours. Allowances for the waste of water from this cause must be calculated, and also that upon the locks, reservoirs, and feeders of canals.

The loss from filtration must depend upon the nature of the strata traversed and of the materials used to form the bed of the canal. When these are homogeneous, the rate of filtration depends upon the surface wetted, the depth of the water, the extent of the permeable strata at the bottom, and upon their degree of saturation. The amount of loss from this cause usually varies from one-half to as much as twice that from evaporation. Instances have been known in which all the water of a canal has disappeared in twenty-four hours; in other cases the depth of water lost has been no less than 2 feet 8 inches in that time, even after the canal had been in use for fifteen years; in others the navigation has been suspended for the greatest part of the year. When such serious losses do occur, the best remedy appears to be to line the bottom of the canal with a bed of concrete executed in hydraulic lime. Puddling is but an inferior substitute, for the clay of which it is mainly composed is liable to shrink and crack with great heats, and thus takes on itself the action it was introduced to remedy. On the Canal St. Quentin, where the filtration took place to such an extent as to render navigation impossible during eight months of the year, concrete was introduced in the manner shewn in the following sketches; a small step being formed in the angle to prevent the clay lining from slipping. In ordinary cases an allowance for filtration of 2 inches per 24 hours may be considered as ample; but it must be observed, that the first time water is turned on, even upon a water-tight bed, the level will fall at least 4 inches in the 24 hours; and this loss will be repeated every time the canal is laid dry for repairs.

Fig. 1.

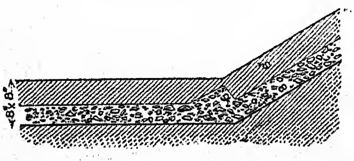
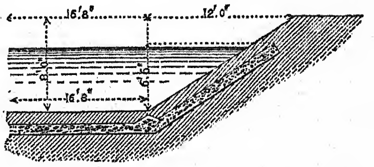


Fig. 2.



Canal St. Quentin.

Loss from Locks.

17. The defective execution of lock-gates gives rise to a very serious loss of water. Even when they are new, the weight of water in the upper basin forces the water through the meetings of the heel and mitre posts. After some years' wear this necessarily augments, and attains sometimes such importance as to give rise to a loss of not less than 10,000 feet cube per 24 hours from one lock. In order to be sure of a constant supply of water, it is advisable to establish the reservoirs, with a view to prevent such a loss.

Loss from cleaning the Bed of a Canal.

18. The loss of water occasioned by the repairing and cleansing the beds of canals depends greatly upon the length of time during which they are left dry. Every reason, economical or sanitary, requires that this should be as short as possible; for not only is the navigation suspended during these operations, but also there are dangerous exhalations from the slimy bed, and at the same time the latter is exposed to crack, to shrink, and dry, in proportion to the time it is laid bare. Under the most favourable circumstances, as explained in the last paragraph, there must be a

great loss from the new filtrations. A saving of water may sometimes be effected by cleansing one bay or basin at a time, working upwards; so that the immediate loss may nearly be confined to the contents of the longest basin, with the filtrations in addition.

Loss by Lockage.

19. The loss occasioned by the passage of boats through the locks must depend not only upon their number, but upon their proximity to one another, and also upon the relative directions in which the navigation takes place. A tolerably accurate estimate may be formed upon the supposition that every passage through a lock of the ordinary dimensions of large canals will require nearly 18,000 cubic feet of water. This quantity is far more than is absolutely necessary to restore the level in case of passage, but there is always a waste from the defects of the gates or from carelessness of the lock-men, which renders it advisable to count upon double the quantity absolutely required.

When numerous boats remain in a canal, they give rise to a displacement of water which can only be compensated for by a supply from the upper levels. The quantity necessary to establish this compensation has been taken at $\frac{1}{16}$th of that required for the passage of the locks.

Reservoirs.

20. The dimensions of the reservoirs must be calculated so as to meet all the future possible requirements of the navigation. The upper basin, or summit-level, should itself be established in such a position as to act to a certain extent as a reservoir, and consequently occupy the lowest position in the mountain range. But there is often an inconvenience in deriving all the supply from one source, namely, that the water is likely to attain a velocity susceptible of injuring the works, or at any rate of retarding the navigation. Artificial reservoirs, wherever placed, present great advantages over the irregular supplies from springs or streams, as it is easy to regulate the flow from them in such a manner as to maintain a constant level in the canal; whereas streams furnish occasionally ten times as much as at others, and are often exposed to periods of perfect drought.

Direction of Canal.

21. The preceding calculations of the loss of water, &c., suppose that the Engineer has already traced out, provisionally, the direction to be followed by the canal, so as to form an approximate estimate of the length and the number of locks to be constructed. Having also ascertained the probable supply of water, the definitive line must be chosen. In leaving the summit-level, the two descending branches follow the valleys of the water-courses which determined the position of that point. If it be possible, that side of the valley should be chosen which presents the fewest affluents and is the least intersected by common roads; bearing always in mind that circumstances may arise in which it is desirable to use the secondary streams as feeders for the canal.

Rocky soils are the most favourable for the foundations of locks, bridges, or such works; but they render the earthworks very expensive. If they be of a porous or fissured nature, they are likely to cause dangerous filtrations. Schistose rocks decompose under the combined actions of air, water, and frost; and then they pass into a soft mud. If the soil be clayey, it will be sufficiently solid for the foundations of the locks, and it will be well adapted to retain water, and easily excavated; but if the beds be inclined, or if springs filter through at any intermediate height, such clay soils are exposed to dangerous land-slips, certainly the most serious difficulty to be met with in the execution of engineering works.

Whenever it becomes necessary to pass from one side of a valley to another, the position must be chosen so that the passage be as short as possible, and that the land upon the banks of the canal present sufficient solidity. The curves by which the junctions between the changes of direction of the course of a canal are effected

must be made as easy and of as large a radius as is convenient. They must at least be such as to allow two boats to pass one another easily.

In all civilized countries many difficulties arise from the complicated relations of property, which render it impossible to carry out the works in the most desirable directions. Too much care and pains cannot, therefore, be bestowed upon the preliminary investigations of the country to be traversed. Maps must be made, indicating the boundaries of every parish and township, what counties the canal is intended to traverse, the proper names of the owners and occupiers of the land. All the public and private roads, paths, or communications which exist in the direction to be followed; all brooks or streams, and particularly such as lead to or supply a mill; the situation of any houses, villages, or towns, upon the line, and even within some miles of the intended canal, require to be carefully ascertained with the greatest accuracy.

Position of Locks and Bridges.

22. A complete plan of the line being made, indicating all the lateral cuts, branches, feeders, and reservoirs, the precise position of the locks, bridges, and culverts must be definitively arranged. Those of the locks will, to a certain extent, be regulated solely by the nature of the ground, and should be chosen at the bends in plan, or at the points where the natural level of the country changes rapidly; and it is desirable that the positions of locks coincide with those of the bridges. In such cases there is a considerable saving of masonry effected by making the wing-walls of the locks serve as foundations for the abutments of the bridges. At the intermediate positions, bridges must be erected so as to cause as little derangement of the existing traffic as possible. The dimensions of culverts must be sufficient for the discharge of any floods likely to occur in the secondary valleys: at times they may be obviated by means of new channels opened to concentrate the flow of several small streams into one, situated in a more favourable position for the establishment of a new outfall.

The proportions of locks per mile of canal is necessarily very variable. A table is subjoined of that which is found to exist upon some of the most important canals in our own country, in France, and in America. It is, however, only given as an approximation, and as a means of comparing the probable results to be obtained from any new work of the kind. There is one lock in a distance varying upon the several canals as follows:

ENGLAND.

On the Rochdale	one lock in	0·33	miles English.
Mersey and Irwell	,,	0·60	,,
Grand Junction	,,	0·65	,,
Thames and Severn	,,	0·67	,,
Kennet and Avon	,,	0·88	,,
Forth and Clyde	,,	1·03	,,
Birmingham and Liverpool	,,	1·08	,,
Birmingham	,,	1·10	,,
Grand Trunk	,,	1·25	,,
Leeds and Liverpool	,,	1·43	,,

FRANCE.

On the Canal	du Nivernais,	one lock in	0·66	miles English.
,,	de Bourgogne	,,	0·80	,,
,,	du Rhin	,,	0·87	,,
,,	du Centre	,,	0·87	,,

On the Canal du Haut Rhin one lock in	. .	0·93	miles English.
,, de Berri ,,	. .	1·28	,,
,, de l'Ille et Rance ,,	. .	1·64	,,
,, du Midi ,,	. .	1·89	,,
,, de St. Quentin ,,	. .	2·12	,,

On the canal from the Rhône to the Rhine a lock occurs in every distance of 1·31 of an English mile.

In America, upon the Erie Canal, one lock occurs in every distance of 4·36 miles; on the Chesapeake Canal, one in a distance of 4·61 miles.

Telford on Springs.

23. Telford laid great stress upon the necessity which existed for a series of investigations into the nature of the substrata and the heights to which land-springs might rise. He cautioned Engineers, very properly, against a dangerous error that the latter may become available for the supply of the canal. It often happens, as he justly observes, that such springs, from having a variety of other vents or outlets at, or very near to, the same level, are incapable of being dammed or raised higher than they were before. When the canal is filled with water to a higher level, the course of such springs can be reversed, and the porous strata, through which they passed, may serve to absorb and discharge the water at other places to a very fatal extent. Land-springs, or such as run only in winter, have generally the same effect, and in summer as copiously take in water, when their own source fails, as they before discharged it.

After all these preliminary investigations have been made, it will be necessary to revise the whole plans, in order to secure an equalization between the cuttings and embankments; to ascertain that the locks, bridges, and other works are placed in the most advantageous positions; and that the curves as well as the general direction of the canal are of the most favourable nature. The preliminary estimates will have to be based upon the results of this last and definitive plan.

Execution of Works upon Canals.

24. *Earthworks.*—When the works are really to be commenced, the resident Engineer must proceed to trace accurately the levels of the different ponds or reaches of the canal, and to put in level-pegs, more or less, according as the ground is more or less undulating as he proceeds. In canal, as in railroad earthworks, the great object to be attained is, that the stuff dug from one part of the work shall, with the least labour or distance of moving, exactly supply or form the banks that are to be raised in another; so that upon the completion of the works no spoil-banks, or heaps of useless soil, shall remain, or any ground be unnecessarily rendered unfit for cultivation by the excavations or pits of the side-cuttings. Six different cases will be ound to occur in the cutting or forming of a canal, as in the accompanying sketches; the main principles, to be observed in all, being to economize the removal and transport, to a distance, of material; and in cases where deep cutting occurs, to make a berm which shall prevent the disintegrated portions of the rocks on the upper side from falling into the canal: any streams likely to fall into it from the upper lands must also be intercepted if they be likely to bring down any alluvial matters.

The Engineer will find abundant instances of diagrams 4, 7, and 8, in all their degrees, and in which there will be either a want of stuff to form the banks, as in 7, or a redundancy from the deeper cutting, as in 4; and the perfection of his skill will be shewn in so conducting the line that every embankment (as at 7) shall have deep cutting at both, or, at least, one of its ends, to furnish the extra stuff with the least expense in moving it. In like manner, every deep cutting (as at 4) should have

embankments at one or both of its ends, to receive the extra stuff. In practice, an infinite variety of such cases will occur, rendering necessary great skill on the part of

Fig. 3.

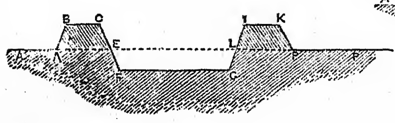


Fig. 4.

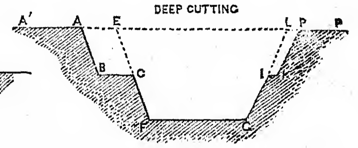


Fig. 5.

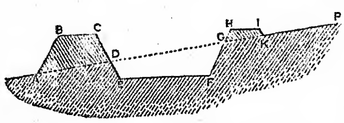


Fig. 6.

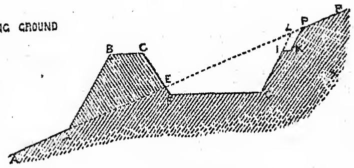


Fig. 7.

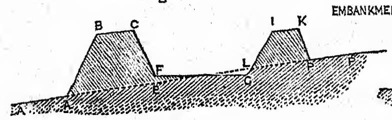
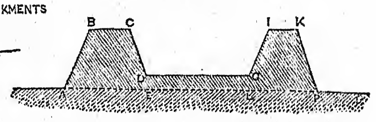


Fig. 8.



the Engineer in laying out the line so as to balance the amounts of his earthwork, and to avoid inconvenient sharp curves, such as Telford so strongly censures, in many English canals.

The first operation in staking-out the ground will consist in tracing the outside line to be followed by the cutting or embankment when completed; and subsequently in staking-out the centre line. The positions of the different works to be erected must then be indicated, and provision made to secure, in one case the earth necessary to back up the bridges or locks, and, in the other, to widen out the banks when it becomes necessary to erect a toll-house, warehouse, or other building.

In narrow canals, or branches of that description, wider places must be provided at intervals, to allow the barges to turn and to lie in whilst others pass them. These must be so situated that bargemen can mutually see each other approaching, and be able to pass one another without being obliged to drag their boats back again to a passing-place. At the same time they should be chosen in such low positions as will admit of widening the canal without much extra expense.

When the line is staked-out, the foundations of the locks and bridges should be immediately put in; the several drains and culverts executed as rapidly as is consistent; any water-pipes for the supply of neighbouring properties laid down at such depths as to preclude any possibility of their injuriously acting upon the canal. The vegetable soil should also be carefully removed from the whole surface of the ground.

Puddle.

25. Telford, and perhaps the bulk of our Engineers at the present day, attached very great importance to the study of the means of rendering canals impermeable by means of puddle; and they consequently devoted much attention to ascertaining whether materials fit for the purpose were to be obtained easily. The introduction of the use of concrete made of hydraulic lime has simplified the question in many cases; for its expense, although considerably greater in the first instance, is more than compensated for by the economy it introduces by effectually stopping filtrations.

The eventual saving, in countries at least where lime is at a reasonable price (every lime being susceptible of becoming hydraulic to any required degree of energy), is, however, decisive upon the question. Yet in countries like Holland, and in some of our own Colonies, the use of puddle may still be necessary. Puddle consists of clay reduced to a semi-fluid state by working and chopping it about with a spade, while water just in the proper quantity is added, to render the mass homogeneous, and so much condensed that water cannot afterwards pass through it, or only so pass very slowly. The best puddling stuff is rather a lightish loam, with a mixture of coarse sand or fine gravel in it: very strong clay is unfit for the purpose, on account of the great quantity of water it will hold, and its disposition to shrink and crack as this escapes. Vegetable mould or top-soil is very improper, on account of the roots and other matters liable to decay and leave cavities in it, but more on account of the temptation that these afford to worms and moles to work into it in search of their food. Where puddling stuff is not to be met with containing a due mixture of sharp sand or rough small gravel stones, it is not unusual to procure such to mix with the loam to prevent moles and rats from working in it; but no stones larger than about the size of musket-balls ought to be admitted. Telford states that the operation of chopping up and beating the puddle consolidates it to such an extent, that it only occupies two-thirds of its original bulk; and that the commonly received opinion in his day, that the first coat should be allowed to dry before the second and succeeding ones were applied, was not founded upon any rational grounds. Whatever be the expense of rendering canals impermeable, it is nevertheless so evidently the interest of all parties connected with them, either as shareholders or neighbours, that they be rendered so, that it is to be desired some stringent legislative enactments were enforced to insure their fulfilling the above condition.

Observations to be made upon execution of works.

26. In England and in the United States the execution of large public works is generally carried out by contractors, who undertake the whole or portions of the work. In France and Germany, however, and doubtlessly in our own East Indian and other Colonies, that useful class can hardly be said to exist; at any rate, it is very difficult to find contractors possessing the capital and skill required to carry on works according to English practice. Under these circumstances, the Engineer is forced to treat, as it were, directly with the sub-contractors or piece-workmen, or even to have some works executed by day-labourers. His duties in this case become complicated by the financial parts of the execution, and require great knowledge both of the manners and mode of treating workmen, and also of the amount of work they ought to do. Under any circumstances, and even when a contractor is employed, it is desirable that careful observations should be made upon the number of men employed, and upon the mode of carrying on the works. Too strict a superintendence of the different operations is impossible; and the system of leaving the contractor almost master, so to speak, which is the unfortunate tendency of our actual method, should be carefully guarded against. In letting earthworks, all barrows, wheeling-planks, horsing-blocks, and other implements, are generally found by the Company. Formerly, in England, a stage of wheeling was considered to be from 20 to 25 yards in length, and the price per cubic yard was fixed in proportion to the number of stages the soil was to be moved. The French Engineers reckon the stage at 33 yards upon the level, and at 22 yards when upon an incline of 1 in 10. Where the distance to be traversed exceeds 100 yards, horses may be economically employed. Upon railways, it may be added, the use of a locomotive is preferable if the lead be above $1\frac{1}{4}$ mile.

Consolidation of Embankments.

27. When the canal is to be carried upon an embankment, it is necessary that the earth be well consolidated before it is attempted to turn in the waters. The French

Engineers insist that all such works be executed in layers of not more than 6 inches in thickness, and that each course be well rammed, after being previously watered with lime-water.

Bottom or Bed of Canal.

28. If the bottom of the canal be puddled, it must be executed in several courses, under the most careful and incessant superintendence. The courses should never exceed from 10 to 12 inches in thickness; and when the whole is completed, the puddling must be brought to a total thickness of 3 feet. When the top course is set, a layer 18 inches or 2 feet thick of the common soil or stuff should be laid evenl upon it, and the bottom levelled: this covering of the bottom should be rather dry, and not in large lumps, or with great stones or sticks in it. The sides are not usually puddled to so great a thickness as the bottom: 18 inches is the ordinary thickness, which is again covered over with the common soil to prevent the slipping of the puddle; and it may be here repeated, that when the extra depth of excavation required for the puddling, and the amount of labour involved in its execution, besides the very doubtful nature of the results attained, are taken into account, the advantages of employing it instead of a good hydraulic concrete, are more than questionable. The solution of this question is, however, one which must entirely depend upon local considerations, and therefore admits of no absolute decision *à priori*.

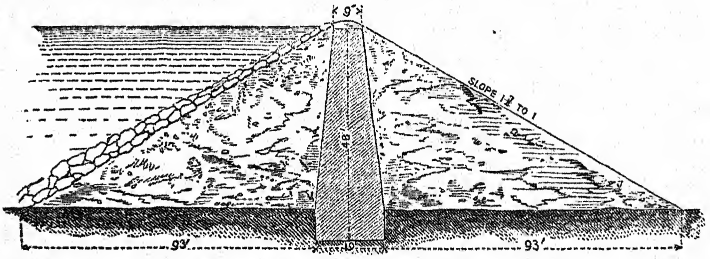
Whatever be the means adopted to insure the impermeability of the bed of the canal, the attainment of that state must be a *sine quâ non* for its economical working. All authors upon the subject, all the experience of the most scientific Engineers, are in accord in this respect. Telford repeats, again and again, his cautions upon the necessity of its being executed in the most perfect manner, and also upon that of preventing any springs from rising up through the bottom.

The management of spoil-banks (or the deposits of earth extracted from the cuttings in excess of the embankments), and of the side-cuttings (or excavations to furnish earth when the cuttings are not sufficient in quantity, or would require too heavy an expense of transport), is precisely the same with canals as it is with common roads or railroads. The mounds produced by the former should not be formed until the vegetable soil has been removed from the position they are to occupy; when dressed off, the same soil should be spread over the top, to encourage the growth of vegetation.

Works of Art upon Canals.

29. *Reservoirs.*—Reservoirs ought to be entirely distinct from the navigable parts of the canal, in whatever position they may be placed in reference to the summit-level.

Fig. 9.

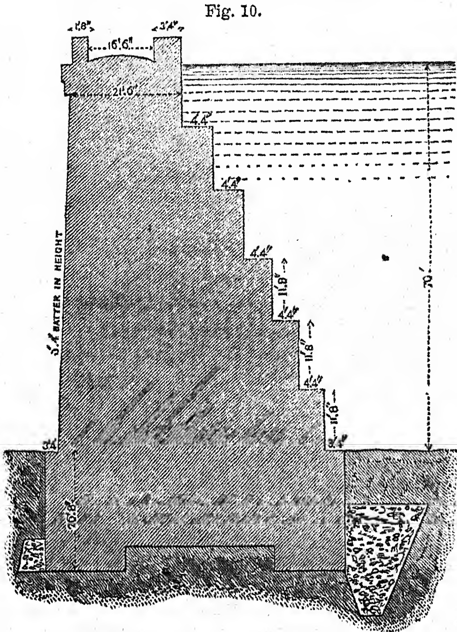


Marsden Reservoir, Huddersfield Canal.

It frequently happens that it is necessary to lay dry the whole length of the canal, and under such circumstances there would be an evident advantage in isolating the reservoirs. If any natural ponds are to be met with, they should be made use of;

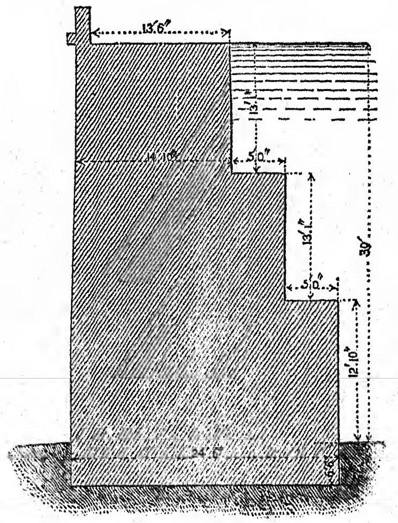
but considerations of economy in the original construction must not lead to the neglect of furnishing artificial means of supply, in case the position of such ponds be not adapted to the wants of the canal.

Fig. 10.



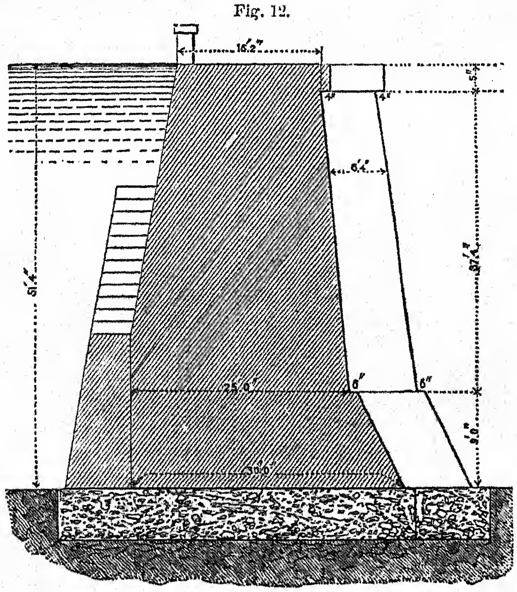
Canal de Bourgogne—Reservoir de Gros Bois.

Fig. 11.



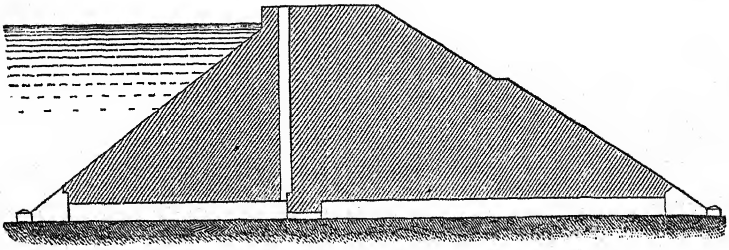
Reservoir of Glomel—Nantes to Brest.

Fig. 12.



Reservoir of Lampy—Canal du Midi.

Fig. 13.



Reservoir of Torcy.

Position of Reservoirs.

30. When reservoirs are not formed by means of natural ponds, they are placed in valleys, the heads of which are dammed across so as to retain all the waters which may fall upon the upper country. It may happen that a considerable supply of water is to be derived from a parallel secondary valley, by carrying the stream through the separating ridge in a tunnel. In the main valley, the position of the dam must be chosen at the point where the valley is the narrowest, or where the strata on which it is to be constructed are such as to be able to resist the tendency to crush, or to slip, caused by such enormous insistent weights.

The conditions necessary to be observed in the construction of reservoirs, as far as regards the quantity of supply, have been already discussed. The water they furnish must be at all times available for refilling the canal, and must also be so free from alluvial matters, so devoid of velocity, as not to be likely to injure the banks or to choke up the canal. There must be provided, then, in every reservoir : 1st, A dam to close the head of the valley, in which means to let off the water, and to regulate its flow, must be provided. A parapet, varying in height according to the surface of the basin and the prevailing winds, must also be provided. 2ndly, A waste weir, or overflow, to carry off any surplus water which may enter the reservoirs. 3rdly, An aqueduct at the bottom, through which any muddy water may escape, or by means of which the reservoir may be emptied in case any repairs are required. 4thly, A temporary basin in which the mountain streams may deposit the mud and gravel they bring down.

Dams.

31. Dams of reservoirs may be executed in various manners, either of earthwork, lined with puddle, and consolidated on one or both sides by a paving of dry stone pitching ; or by an embankment faced on both sides by walls ; or finally by a wall. They are sometimes executed of a curvilinear form in plan, presenting their convex side towards the interior. Reservoirs have been executed in England and France with dams of not less than from 40 to 70 feet in height, which have stood very well. Some of the dams executed by the Moors in Spain are of more extraordinary dimensions still : the dam of the Fountain Reservoir of the Croton Aqueduct at New York, which covers a surface of 400 acres, is not less than 38 feet in height, and on the Rideau Canal there is one 60 feet high.*

When the dams of reservoirs are executed with an embankment between two or more walls, there is great danger to be apprehended from the swelling of the earth upon its imbibing water. The thickness of the walls has to be so much augmented to resist this action, that there does not appear to be any real economy in the mixed system. Under usual circumstances, it appears preferable to form the dam entirely

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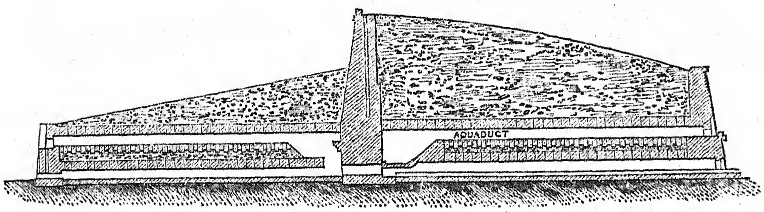
* See vols. i. ii. and iv. of Professional Papers of the Corps of the Royal Engineers.

in masonry, especially when good hydraulic lime is easily obtained. The dam should be made of middling-sized materials, and a coat of hydraulic concrete interposed between it and the water.

Fig. 14.



Reservoir of Couson. Canal de Gisors.

Whatever be the mode of constructing the embankments and dams of the reservoir chosen, it is an indispensable condition that the soil upon which it is to be built be of a nature not to allow of unequal settlements, and that it do not permit the passage of water. To secure these conditions it has often been necessary to carry down the foundations to such a depth as to require as much masonry below as above the natural level of the ground ; in some cases as far as 50 feet.

Telford recommends, that if the strata upon which the reservoir is to be formed should be of a porous nature, such as to allow of the infiltration of the water, the whole of the bottom of the valley should also be puddle-lined. The face of the dam must also in such a case be puddled towards the water, and it is even advisable to make an extra puddle-ditch in the centre, to guard against any accidental slip of the face lining. There are few operations in canal-making of more importance than those necessary to economise water in reservoirs, and the enormous expense entailed by the above-named precautions, to insure their impermeability, will shew the necessity for extreme caution in the choice of their positions, as well as for an intimate knowledge of Geology.

In executing the dams, trenches should be dug in the foundations, so as to break their horizontal line into a series of steps. Such a course offers a greater resistance to the lateral thrust of the water, and renders the dam less liable to slip. Of course the same precaution must be taken for the sides. Another advantage in these steps is, that they break the direction of any stream which may filter through the bank, and facilitate the deposition of any earthy matter carried by the water, causing the crack 'to take up,' to use the workman's phrase.

If the dam be executed in earthwork, it should be made from 13 to 16 feet wide at top, with slopes varying from $1\frac{1}{2}$ to $2\frac{1}{2}$ base to 1 in height. The best mode of making such dams appears to be to employ clay mixed with a certain proportion of sand ; this should be watered at every course with a little lime-water, and well rammed, taking care to leave certain asperities, or toothings, upon the face of the different layers, to prevent the upper ones from sliding upon those beneath them. It is also necessary to follow on the work rapidly, to prevent the lower courses from drying before the upper ones are added.

Reservoirs, if enclosed by a dam of masonry, require precisely analogous precautions ; the filtrations must be prevented as far as possible by stepping the foundations ; and care must be taken to break the horizontality of the beds. If the length of the dam be considerable, it will be necessary to introduce many counterforts ; not so much for the purpose of saving masonry in the dam itself, as to resist the

tendency of long bodies of walling to assume a catenary form under constant and heavy pressure.

The size of the reservoirs of the more important canals is such that they become, in fact, lakes of still water; and as their positions are often of a nature to expose them to the violent action of the prevailing winds of the mountain gorges, it is necessary to carry the dam about 5 feet above the water-level, to prevent the waves from washing the upper portions of the enclosure. Precautions must be taken, in the event of the waters overflowing the crown of the dam, to prevent injury to the structure. An accident of this nature took place during the execution of the works for the Croton Aqueduct, when the floods, rising over the dam in an extraordinary manner, carried away in a few hours the whole structure, and spread death, ruin, and desolation throughout the course of the stream.

Thickness of Walls.

32. From the movements remarked in the masonry of some dams, it would appear to be necessary to give the walls double the thickness required by the strict application of theoretical rules. Indeed, in such works the tendency to slip upon the bed complicates the conditions of equilibrium to a serious extent; it is, in fact, greater than the tendency to turn over on the extreme edge. Representing the height of the water by h, the thicknesses which appear to be the most advisable to give to the dams of masonry at the following points in their height, are, x being the thickness sought:

$$\begin{aligned} &\text{At the top,} && x = h \times 0{\cdot}30 \\ &\text{In the middle,} && x = h \times 0{\cdot}50 \\ &\text{At the bottom,} && x = h \times 0{\cdot}70 \end{aligned}$$

Such thicknesses are, perhaps, rather in excess; but the terrible consequences arising from the bursting of a dam, and the more perfect impermeability of a large mass of masonry, should rather induce a preference in this direction.

The importance of reservoirs to the regular working of canals may be judged of by the colossal constructions executed, in dry warm climates especially, to insure their constant supply.

The Birmingham Canal has a reservoir of 80 acres surface, with a depth of 45 eet at the head of the retaining bank. That of the Union Canal of Pennsylvania is not less than 730 acres superficial, by an extreme depth of 40 feet, and it holds 572,509,000 cubic feet of water.

The principal reservoirs in France are specified in the following Table, with their height of water, capacity, &c.

Canal.	Reservoir.	Nature of dam.	Height of water.	Capacity.
Du Midi	St. Fériol	Earth and wall	105 ft. 0 in.	223,090,000 cubic ft.
De Bourgogne	Gros Bois	Wall	69 ,, 6 ,,	300,510,000 ,,
,, ,,	Cercey	Earth	39 ,, 3 ,,	130,900,000 ,,
Nantes à Brest	Vioreau	Wall	33 ,, 0 ,,	262,395,000 ,,
Du Centre	Torcy	Earth, lined	36 ,, 3 ,,	83,300,000 ,,
Du Briare	Grande Rue	Earth	26 ,, 6 ,,	189,000,000 ,,

The reservoirs of the English canals are rarely of such colossal dimensions as those of France; but the new waterworks reservoirs of some of our northern cities and of our colonies may be compared with them. The capacities of a few of these structures are subjoined:

Canal and Reservoir.	Capacity.
Manchester and Macclesfield . . .	291,915,669 cubic feet.
Turton and Entwystle	100,000,000 ,,

Belmont	75,000,000	cubic feet.
Manchester Waterworks	584,866,716	,,
Liverpool, Rivington Pike . . .	506,581,059	,,
Yan Yan, Victoria (in round numbers) .	1,000,000,000	,,

Distribution from Reservoirs.

33. For the service of the canal, the water is usually drawn from the reservoirs by means of a series of sluice-gates, placed at different levels to draw off the water in such a manner as to prevent its acquiring any velocity from the head above it. In some reservoirs the sluices are replaced by large cocks, so constructed as to be worked by screws; but whatever means may be adopted for distributing the water, it is necessary that the flow be kept under the most accurate and instantaneous control.

Occasional Resources.

34. It very frequently occurs that springs, streams, or rivers, in the course of a canal, may be advantageously substituted as a source of supply for the more expensive means furnished by reservoirs. This method is more commonly employed in the United States, where the greater portion of the canals are replenished by feeders from such accidental sources. In Belgium and Flanders it frequently happens that a set of locks occurs in such immediate proximity to one another, that there is advantage in returning the water, passed through the locks, to the upper level, by means of steam or water power. Local considerations must, however, decide the question as to what system should be adopted in every particular case.

35. When, therefore, feeders from side-streams are to be made use of, their beds should firstly be rendered as impermeable as possible; the new course of the feeder should be made as direct, and the fall be as small, as may be required to conduct the water with an uniform velocity suitable for the purposes of the canal. As with the streams directed into reservoirs, care must be taken to prevent them from carrying any impurities likely to obstruct the bed of the canal. The use of streams for mill-power renders their application for the supply of canals often extremely difficult. In certain positions springs form the most economical means for meeting the losses of the navigation. In low alluvial plains, situated in large basins of the older and more impervious strata, and in some portion of the rocky districts through which the summit-level is carried, it is very common to meet with springs of great abundance. In the former case their overflowings may be advantageously employed in the lower levels of the canal: in the latter it may often admit of deliberation whether it would not be more economical to execute the summit-level in tunnel, so as to be able to meet and employ the springs which so frequently occur in the interior of the hills to be traversed. Such questions again require an intimate knowledge of Geology.

In some cases the depth of the summit-level pond has been increased for the purpose of making it serve as a reservoir. But Telford justly objects to this course, on the ground, that inasmuch as the level of the lock-sills must be established with reference to the lowest state of the water, every time a lock is filled it causes a waste; and it therefore appears desirable to make the bottom level of the reservoir at such a height above that of the canal as to allow of its waters flowing easily into it whenever a deficiency is felt from any cause whatever.

The section and the fall to be given to a feeder must be calculated upon the formulæ which regulate the calculations upon the flow of running water. In practice, however, it is usual to maintain the fall between the limits of from 1 to 5 in 10,000, unless the peculiar position of the streams which supply the feeders be such as to require an increase of velocity; and it is obvious that in order to furnish equal quantities, a slight fall requires a larger section, and is objectionable, because it is more exposed to evaporation and to filtrations. A sharp fall gives too great a velocity to the stream; it is likely to injure the banks, and especially to carry down troubled waters into the basins.

Navigable Feeders.

36. If the feeders are intended to be used for the purposes of navigation, a condition which often arises in France and America especially, their dimensions must be regulated with reference to the boats they are to receive. Their fall must, however, not be more than is necessary to give the waters a velocity not exceeding 12 to 14 inches per second.

The same precautions alluded to for reservoirs require to be taken with the feeders, in order to prevent their supply exceeding the wants of the canal. Waste-weirs and regulating-sluices must be formed to control the flow; and if the feeders be upon a hill-side, catch-water drains must be formed, so as to allow the mountain streams to deposit the mud they hold in suspension before flowing over into the feeders. It is also recommended to form settling reservoirs from distance to distance in the bed of the feeder itself.

Bed of the Canal.

37. The longitudinal section of the different portions of a canal should be made with a gentle fall, to allow the water to flow with sufficient freedom to compensate for the loss occasioned by passing boats through the locks, or in case it be advisable to leave the bed dry. On some parts of the Erie Canal a fall of 1 inch in a mile was given, whilst in others it was reduced to one-half that inclination: the consequence was, that great vigilance was required to maintain the level of the water when the navigation was active.

Dubuat's formula for ascertaining the proportions of the section of a canal, $R = r\dfrac{8 \cdot 4}{\dfrac{S}{S'} + 2}$, in which R = the resistance in a canal; r = the resistance in any undefined fluid; S and S′, the transverse sections of the canal and of the boat,—would require, supposing R and r to be equal, that S were six times S′. In practice it is, however, usual to make the bottom, or floor-line, of a canal twice the width of the boats it is intended to carry, with an allowance of from 6 to 8 inches play on both sides. The lowest basins, or any intermediate ones where boats are likely to be stationed, require to be widened out according to the nature of the traffic. Sometimes in expensive rock-cutting, or in tunnels, the canal is only made wide enough for the passage of one boat at a time; in such cases the canal must be widened out immediately before arriving at the narrow part. Such extra width must also be given at any sharp curve or sudden change in the direction.

The depth of water must be from 1 foot to 18 inches more than that of the deepest laden barges; because, firstly, the bottom is liable to silt up, and secondly, numerous aquatic plants quickly take root. Such extra depth is also necessary for the compensation required by the lockage of the boats.

The sides of a canal, partly from the shape of the boats, and partly from the nature of the materials of which the banks are formed, have an inclination which may vary from 1·5 to 3 in 1. At the water-line it has been found necessary to make a species of banquette, to break the force of the waves or the shock of the boats, upon the edge of the towing-path. Such banquettes are planted with aquatic plants (the iris, reeds, &c.), to increase their retarding action upon the waves. Another method of guarding the towing-paths is to line the sides with stone pitching: on one occasion cast-iron plates were employed for this purpose.

Towing-paths.

38. Towing-paths should be kept much as before explained; and if the hauling be done by men, the width need not exceed from 4 to 6 feet. When horses are used, it should be from 12 to 16 feet wide: the latter dimension is the one adopted on the United States' canals.

Occasionally the action of the winds may be such as to render it necessary to tow from both sides, to prevent the boat from 'hugging' one bank. In such cases a double towing-path is required, of the same dimension as the normal one. At all times, however, it is advisable to construct a narrow footpath on the opposite side, varying from 4 to 6 feet in width. Should there be any excess of earth from cuttings or excavations, it should be employed in widening out the above paths. The towing-path itself should be made with nearly the same perfection as a carriage-road; and in cases where fly-boats travelling at great speeds are used, the maintenance of these paths becomes a matter of serious expense. When the towing-paths are in deep cuttings, a side ditch must be formed to carry off the rain-water. In embankment, its form and the slope to be given to its external edge must depend upon the materials employed.

Tunnels.

39. When the cutting required to maintain the level of a canal would become too expensive from the mass of earth to be removed, or when there is a probability of meeting copious sources of water in the interior of a hill, tunnelling should be adopted. On some occasions Engineers have preferred to diminish the width of the cutting to merely that required for the passage of a single boat, rather than to execute a tunnel; but local circumstances modify all these questions to such an extent that it is impossible to lay down any invariable rule. Usually, however, if the depth of the cutting be above 50 feet, especially if it be long, there is economy in adopting a tunnel in preference to an open cutting.

The economy of executing a deep cutting for the passage of only one boat is, comparatively speaking, insignificant; for the bulk of the earth removed in such cases is that required to throw out the slopes. The quantity saved is, in fact, only that occupied by the diminished width multiplied by the depth. With a tunnel, however, the expense is diminished in a much more important proportion, for it is relative to the area. The larger a tunnel is, the more difficult are the excavations; the more necessary is it to line throughout, and the more expensive is such lining. At the same time it must be observed, that in addition to the time lost by the boats waiting their turn at either end, small tunnels offer serious impediments to the navigation on account of the resistance of the air and the water.

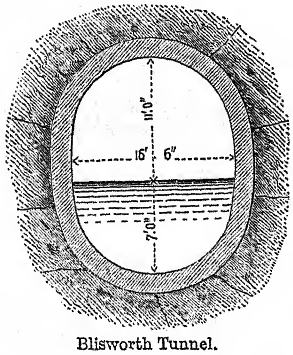
Whether the tunnel be executed for one or two boats at a time, it is usual to give about 2 feet play on each side. On the Canal St. Quentin there are two towing-paths 4 feet wide; but it is preferable to make only one of double that width. In the tunnel executed for the Thames and Medway Canal, and in the Harecastle Tunnel, there is only one towing-path, but of rather smaller dimensions than is desirable. Generally speaking, the boats are drawn through tunnels by men, although horses are occasionally used, in which case the towing-path must be made wider, and a parapet formed. In some tunnels executed by Brindley it is necessary to pass the boats by 'leggers,' a class of men who propel them by pushing against the tops and sides of the roof with their feet, whilst lying upon their backs. In other tunnels the bargeman draws the boat himself by means of a tow-rope fastened to the opposite end; in others, again, there are machines fixed at the ends to haul the boats through.

The height given to tunnels, where boats without masts have to pass, varies from 11 to 16 feet from the top of the water to the intrados of the vault. On the canal from the Chesapeake to the Ohio the height was made 17 feet 3 inches, to allow the passage of the sloops and river-craft.

The forms given to tunnels are very various, being either circular, elliptical, or in the shape of a Gothic arch. Sometimes the sides are inclined towards the top, and

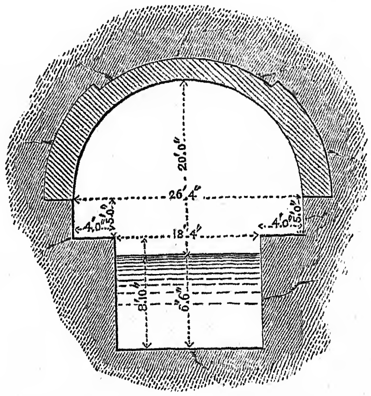
the intermediate portion joined by a segment of a circle. This form appears to be the best when it is not intended to line the excavation with masonry. Such is,

Fig. 15.



Blisworth Tunnel.

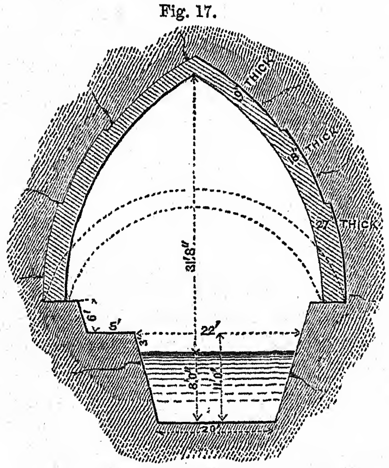
Fig. 16.



Tunnel, Canal of St. Quentin.

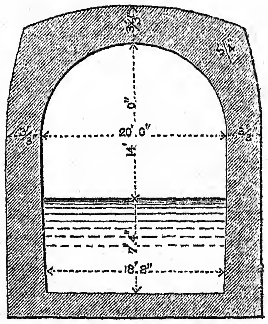
however, rarely the case; for in almost every instance it has been found necessary to resort to that method.

Fig. 17.



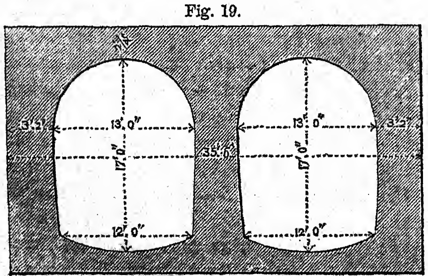
Thames and Medway Tunnel.

Fig. 18.



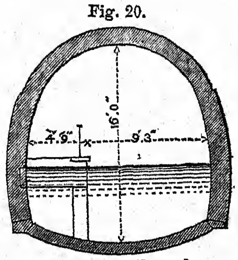
Tunnel of the Ardennes.

Fig. 19.



Thames Tunnel.

Fig. 20.



Harecastle Tunnel.

The form of the sides depends upon the dip of the strata to be traversed, and it is usual to make them portions of circles of great radius. The bottom should be an inverted arch.

The thickness of the masonry must depend upon the nature of the strata and their permeability to water, as well as upon the materials employed in the construction. Experience appears to indicate 3 ft. 4 ins. to 3 ft. 6 ins. as the extreme thickness requisite in the worst ground and for large canal-tunnels: 2 ft. 6 ins. is the limit for smaller ones. The sides should be made from 6 to 12 inches thicker than the roof.

The cost and time employed upon sundry tunnels in England, France, and America, are stated, in round numbers, in the following Table.

Name.	Canal.	Soil.	Length.	Width, &c.	Time.	Cost per yrd. £	s.	d.
Blisworth .	Grand Junction	Blue clay	3080 yds.	$16\frac{1}{2}$ ft. × 18 ft.	...	17	13	0
Foulridge .	Leeds and Liverpool	Partly quicksand	1630 ,,	17 ft. × 18 ft.	...	24	0	0
Thames & Medway	same name	Chalk	$4\frac{3}{4}$ miles	22′ 6″ × 39′ 8″	3 yrs.	32	0	0
Kilsby . .	Lond[n]. & Bir[m]. Railway	Earth, sand, water	2398 yds.	... ...	4 ,,	120	0	0
Harecastle .	Tetney Haven	Clay	2926 ,,	14 ft. × 18 ft.	2 ,,	40	0	0
St. Aignan .	Cn[l]. des Ardennes	Blue lias	300 ,,	19 ft. × 26 ft.	...	42	0	0
Pouilly . .	,, de Bourgogne	Schistose marl	3610 ,,	20 ft. × 26 ft.	8 ,,	86	0	0
Comptich . .	... ...	... ...	1010 ,,	14 ft. × 18 ft.	...	36	0	0
Charleroy .	... ...	... ...	1400 ,,	14 ft. × 18 ft.	...	52	0	0
Tunnel on canal from Chesapeake to the Ohio.			7330 ,,	... ...	...	116	0	0

An important observation to be made with respect to tunnels is, that it is preferable to lengthen the tunnel itself, rather than to have a deep long cutting before entering it. The bottom of a valley is usually ill adapted for the commencement of such works, because in such positions it is difficult to keep out the waters of the valley, or to get rid of the land-springs during the construction of the tunnel.

It may be also stated, that in the piercing of tunnels, whenever the length exceeds from 200 to 300 yards, there is an advantage in working from wells, instead of from the ends only. Such wells or shafts are placed from 40 to 100 yards apart, or even at greater distances, depending upon the rapidity with which it is desired to push the works, and the nature of the strata traversed.

Locks.

40. A lock, or pound, is constructed upon a canal for the purpose of connecting two portions which are upon different levels; and in the part called the lock-chamber the water can be made to coincide with the level of that in either the upper or lower portions of the canal. This is effected by means of two pairs of doors, or gates, one at each end of the lock-chamber; in which gates, or through the side-walls of the chamber, small sluices or paddles are provided, by which water can be let from the higher portion to fill the chamber to the upper level when the lower gates are shut close, or to empty the same to the lower level when the upper gates are closed. It is thus that, supposing the lock-chamber to be at the lower level, a vessel arriving upon the lower portion of the canal enters the chamber, and the lower gates are shut after it. The water is then drawn from the upper level by means of the sluices or gates until

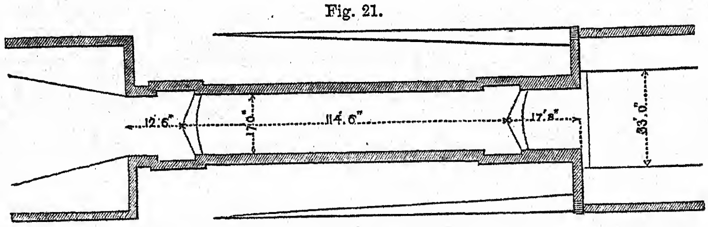
it stands at the same height in the chamber as in the upper level; the gates are then easily opened, and the boat passes into the second portion of the canal. When a boat has to pass from an upper to a lower level, the mode of proceeding is the reverse: the gates are shut upon it, and the water is allowed to run from the upper to the lower level. These operations are called 'locking up' and 'locking down.'

One advantage in uniting several locks in the same locality, so as to facilitate repairs and to concentrate the superintendence, has been already explained. Another reason for such sudden changes in the level of a canal will often be found in the economy they admit in the execution of the earthworks, as by these means either deep cuttings or heavy embankments are frequently avoided. There are, however, certain inconveniences attending the grouping together of the locks in this manner. Firstly, the pressure upon the floor of the lowest chamber becomes dangerously augmented; the tendency to filtration, and to produce upward movements of the floor, is also increased by the same cause. Secondly, such concentrated falls consume more water than would be required if the space between each lock were of the average dimensions. But the saving in superintendence, and the eventual economy of time in the passage of the boats, more than outweigh the importance of these objections, especially in such positions as enable the Engineer to command much water, or where the natural form of the ground is very abrupt.

Fall. 41. The number of locks required to compensate any given difference of level must of course depend upon the fall given to each of them. As a general rule, the falls should be made equal, in order to economize water in the passage of boats. At the summit-level, however, there may occasionally be an advantage in making the fall rather less than in the lower parts of the canal, where water is more abundant. Great falls procure economy of time in the passage, and diminish the number of locks to be constructed, and are worked by fewer men. They require, nevertheless, greater strength of construction, and often entail the necessity of extensive earthworks.

General usage confines the falls of locks between the limits of from 5 to 10 feet for canals having 6 feet deep water: 8 feet to 8 ft. 6 ins. are the usual heights given. Such a lock would require as long a time to pass as a boat would occupy in traversing a distance of one-third of a mile on the ordinary parts of the canal.

Fig. 21.

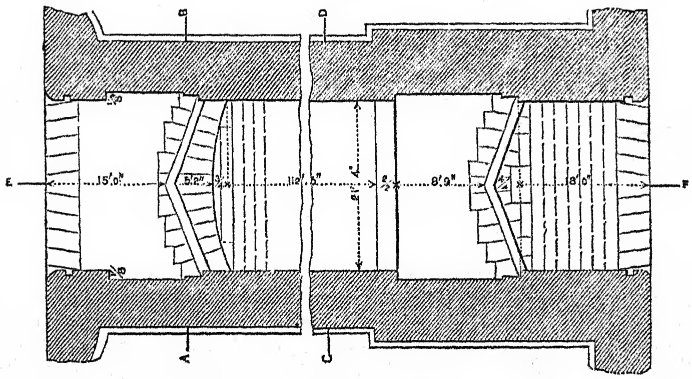


Locks on the lateral Canal of the Loire.

Parts of Locks. 42. The parts of a lock may be considered as being, firstly, the upper chamber, or head, with its gates, and the breast-wall; 2ndly, the intermediate lock-chamber, between the breast-wall and the extreme point of the projection of the lower gates; and 3rdly, of the lower chamber.

Form. 43. On many canals the form of the lock-chambers is made such as to give the side-walls a concave direction towards the water, with the intention of opposing a greater resistance to the pressure of the earth. There does not appear to be anything really gained by this course, because, even supposing the walls do resist the thrust of the embankment more effectually in this shape with the same quantity of masonry,

Fig. 22.



Locks on the Crozat Canal.

locks so constructed waste more water; and moreover the extra thickness required to be given to the floor on account of the increased span nearly equals the saving in the walls. The best modern canals are made with locks of a rectilinear form, similar to those indicated in the above sketches. Sometimes the sides have been executed in slope, but the loss of water at every passage

Fig. 23.

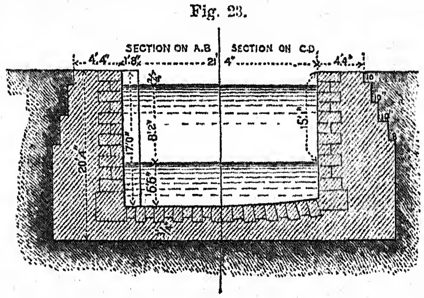
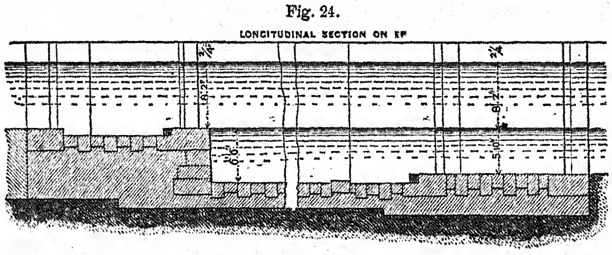


Fig. 24.



is enormous, and the prolongation of the wing walls of both the upper and the lower chambers is often more than enough to compensate for the small saving of the side-walls, especially when the danger of filtrations is taken into account. From these considerations it has become the practice to make the side-walls vertical.

Wood Locks.

44. In Holland and in the United States, lock-chambers have been frequently executed in wood, on account of the high price of masonry. But such works have a very limited duration, and are hardly ever water-tight. In our own Colonies it may sometimes be advisable to adopt the same method, from motives of economy; but it must only be considered as a temporary substitute for a better material. Details of some American wooden locks are subjoined.

The top of the side-walls of locks should be kept 2 feet above the maximum water-line.

Coffer-dam Grooves.

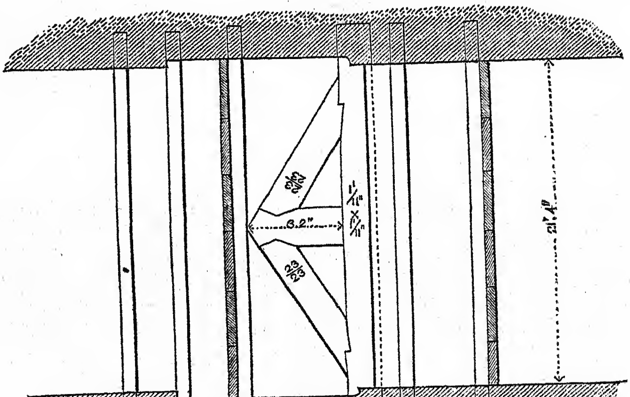
45. To allow means of repairing the works of locks, it is usual to form grooves in both the upper and lower chambers to receive a dam to be thrown across temporarily. Such grooves are made about 8 inches by 8 inches, and of the whole height of the side-walls; they are usually placed from 2 to 4 feet from the returning of the side-walls. A reveal is to be formed to receive each leaf of the gates, about 4 inches deeper than their thickness, and 6 inches longer than the leaves themselves. In order to protect the gates when shut back into these reveals, the side-walls must be carried from 6 to 7 feet beyond them on the upper side; and on the lower the tail-wall should be prolonged according to the width of the opening. Thus for a 15-feet lock, it should be prolonged 12 feet; for an 18-feet lock, 14 feet; for a 20-feet lock, 16 feet, and so on.

Side-walls.

46. In calculating the thickness to be given to the side-walls, the backing must be regarded as a semi-fluid denser than water, and the mass of the walls must be sufficient to resist its momentum. Some Engineers make them equal in thickness to half the height; but the usual practice varies between 0·28 to 0·50 of that dimension. It would appear that 0·40 is the most rational. It is advisable to strengthen the walls below the tail-gates; and when a lock is joined to a dam, as in river navigation, the end-wall to the stream must also be strengthened, in order to resist the weight of water and to prevent filtrations.

The floor of a lock is usually executed with an invert, to resist the upward thrust of the filtrations from the upper level of the canal. It is usual to calculate its thickness upon the supposition that it would be exposed to an effort equal to that produced

Fig. 25.



Wood floor of old Lock on the Crozat Canal.

by a head of water equal to the total depth of the lock. The usual thickness given to the floor of a 16-feet wide lock is 2 feet 8 inches; that for a 20-feet wide lock is 3 feet 4 inches. But whatever thickness be given, precautions must be taken to prevent filtrations from the upper level, by either driving a row of close piling, or by stepping the foundations below the level of the ordinary parts of the chambers, so as to break the thread of any stream which might work through.

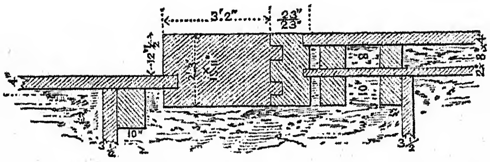
Sills.

47. The sills are laid with a sally to the upper level of from $\frac{1}{6}$th to $\frac{1}{3}$rd of the width of the opening. The most ancient locks were all made with sallies of $\frac{1}{3}$rd to $\frac{1}{4}$th;

modern practice ranges between the limits of $\frac{1}{5}$th and $\frac{1}{8}$th. Professor Barlow states, that the best proportion would be between $\frac{1}{5}$th and $\frac{1}{6}$th, or such as would correspond with an angle of 19°·24.

The sills are raised above the level of the floors of the upper and lower chambers respectively, to form a projection against which the gates are to shut. It is usual to secure the masonry of the body of the sills, and to protect their external edges by means of either wooden or cast-iron clapping-sills, which receive the shocks of the gates. Felt should be placed between the clapping-sills and the masonry. The

Fig. 26.

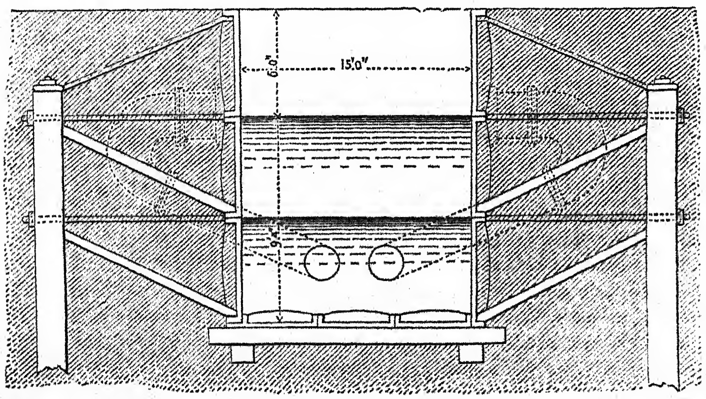


projection of the sills varies from 10 inches to 1 foot, so as to allow the gates to bear for a depth of from 5 to 6 inches, and to afford the same play underneath. The masonry at the back of the clapping-sills is usually executed as a portion of an arch abutting upon the side-walls. Occasionally the whole of the sill is executed in wood-work, as in figs. 25, 26.

Breast-wall.

48. The breast-wall is usually made concave to the lock-chamber, in order to economize masonry, and to receive the prows of boats while between the gates. Formerly the breast-walls were executed in a perfectly vertical position, and their horizontality with the top of the upper clapping-sills and chamber carefully preserved. Of late years, the upper portion of the breast-wall has been made with an incline towards the lock-chamber, and the face has been disposed with a concave front towards the same direction, so as to break the fall of the water from the sluices in the gates. It is usual to give a thickness of from 2 to 3 feet of masonry behind the sills, whatever be the mode of finishing the wall. Care must be taken that no parts of the masonry project, to catch boats during their passage through the locks. The same observation applies to the coping of the side-walls, which must be made flush with their vertical faces.

Fig. 27.

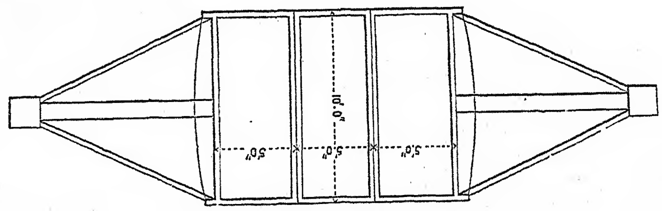


In some modern locks, breast-walls have been suppressed altogether. The upper

level of the canal is deepened with a gradual inclination to the upper chamber, and the first pair of gates is made sufficiently high and strong to resist its pressure. The economy of this system is more than questionable, and the management of the gates much more difficult than in common locks.

The grooves in which the heel-posts of the gates work, the floor they traverse, and the clapping-sills, are the portions of the fixed work of canals which require the greatest possible care in execution. In some cases they are all executed in dressed stone, or ashlar; in others, in wood of the hardest and best description; in others,

Fig. 28.



Cast-Iron Locks.

again, in cast iron. It is indispensably necessary that the fitting of the posts should be perfectly water-tight, and that friction at the bottom of the gates should be prevented.

49. On the Ellesmere and Chester Canal, Telford executed some of the locks entirely in cast iron, upon foundations of little better than running sands. They answered admirably in such positions, but the first cost was necessarily very considerable. Perhaps, in such positions no other system could have succeeded at all, with the exception of wood locks, but these have the serious inconvenience of early decay.

Owing to the agitation produced in the lower chamber by the escape of the water through the sluices, it is advisable to prolong the floor into the bed of the canal, for a distance of 40 feet, for an ordinary fall of 8 feet in the lock. The entry to the upper chamber is also frequently paved to about the same distance, in order to prevent the excavations which might be occasioned by the increased velocity given to the water at the upper gates.

Lock-gates.

50. For the most important canals, the lock-gates consist of two leaves, fitting close, and bearing against the sills at the bottom as well as the grooves in the side-walls. They are generally made of wood; but of late years many gates have been executed in cast or even in wrought iron, or in a compound system of cast and wrought iron and wood. (See Plates II. III. IV. and VII.)

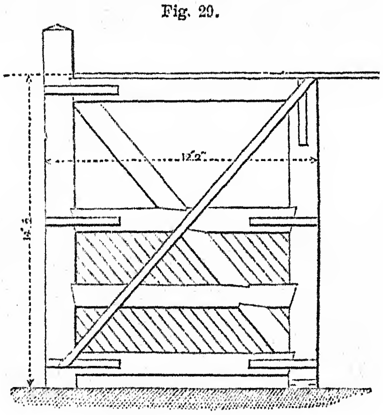
The gates are composed of the upright posts, the turning-post being known as the 'heel-post,' and the meeting one as the 'mitre-post.' These posts are united together by horizontal rails, which support the pressure of the water, and are variable in number according to the height of the gate. Against these rails the planking or wrought-iron plates, which close the gates, are fastened.

The posts are kept about 2 inches clear of the floor, so as not to bear immediately upon it in their revolutions; they are made from 8 inches to 10 inches above the water when the gates are opened by machinery, and somewhat longer when that operation is performed by a long lever on the top of the gates. The lowest rail is usually placed 4 inches above the floor; the upper rail finishes about 4 inches above the maximum water-line. The intermediate rails are spaced according to the effort they have to resist. A raking brace is introduced between the rails when the span is

great, and a wrought-iron tie joins the foot of the mitre-post to the top of the heel-post, to prevent the frame-work from giving at the foot. As the load of the water in a lock presses with greater weight at the bottom than at the top, it follows that the lower rails must be kept closer together than the upper ones, so that the resistance may augment with the effort. In the gates for a lock 17 feet wide with an 8-feet lift, it is usual to make the posts and top and bottom rails of the lower gates about 12 inches deep by from 11 to 12 inches wide; the four intermediate rails are about from 10 inches deep to from 9 to 11 inches wide. The upper gates are made with posts and top and bottom rails 11 inches square; the one or two intermediate rails being in proportion. The tenons have one-third the width of the rails, and enter the post to half its thickness.

When the gates are planked, the least thickness that can be given is 2 inches, or it would be impossible to caulk them. Sometimes the planking is applied horizontally, sometimes diagonally. To obviate the effects of any obstruction in the bottom of the chamber upon the solidity of the framing, it is usual to let in wrought-iron squares, flush with the wood-work, and bolted through at the meeting of each rail with the

Fig. 29.



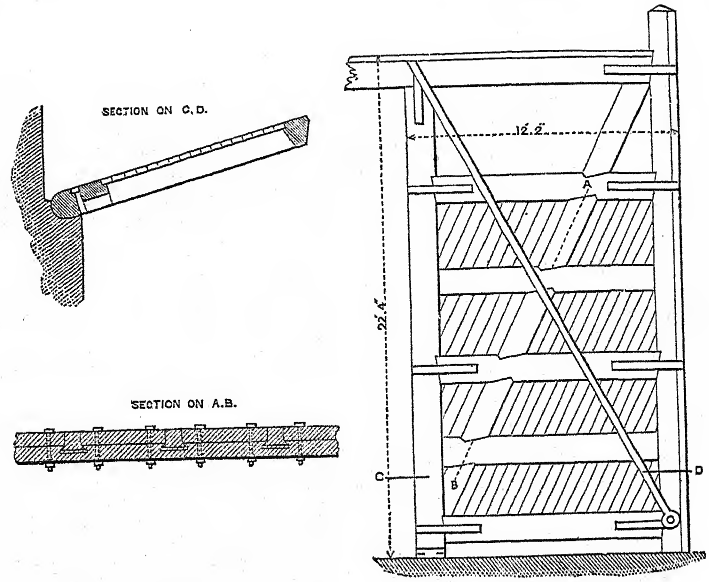
Elevation of Upper Gates.

upright posts. These squares are of iron, from 2 to 3 inches wide by from ½ to ¾ inch thick; the tie from the foot of the mitre to the top of the heel-post is of iron, from 5 to 6½ inches wide by from ¾ to 1⅝ inch thick.

It is important in setting out the frame-work of lock-gates to keep the unsupported extremity about 2 inches higher than it is required to be in execution. This difference will barely compensate for the shrinking of the framing.

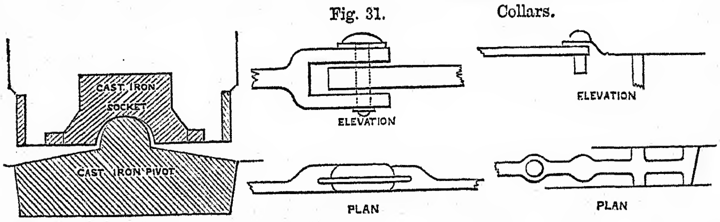
The heel-posts turn upon a metal pivot, working in a metal socket; the former being let into the floor of the chamber, and the latter into the post, which must also be shod with a wrought-iron hoop. In some of the ancient locks the socket was in the floor, and the pivot upon the heel-post; but it was found that the mud in the canal choked up the socket very rapidly. The upper part of the heel-post turns in a collar, made with the hinges, and secured into the land by a set of long wrought-iron anchors let into the masonry. If the posts do not mount for the purpose of receiving levers, they may work at the top upon a pivot concentric with the lower one. The size of the collars is usually from 3 to 4 inches wide by ¾ to 1¼ inch thick; the land-ties, or anchors, are 5 feet long by from 1½ inch to 3 inches square, with tieing-down bolts 3 feet long.

Fig. 30.



Elevation of Lower Gates.

Fig. 31. Collars.



Mr. Barlow recommends that in large lock-gates the leaves should present a curvilinear section in plan, because such a form presents a greater resistance for the same cubic quantity of wood. Theoretically the best form appears to be that resulting from a portion of a circle passing through the points found by the pivots and the sally of the sail. He further recommends that in practice the form of a Gothic arch should be preferred, making the apex from 1 foot to 18 inches beyond that of the circle so ascertained. The objection to this form of gate is, that it is difficult to find wood with a natural curvature suitable for the purpose. When cast or wrought iron is used, this form should be adopted.

Sometimes, when the gates are of great height, they are made in two portions, to facilitate the opening. It has also been proposed to execute a portion of the upper part with hinges, to allow of its being thrown down towards the end of a lockage, for the purpose of expediting the operation of filling the chamber.

Sluices.

51. The water is passed from one level of the lock to the lower one by means either of sluices formed upon the gates themselves, or by small culverts passing from one level to the other, or by syphons. The usual proportion of the waterway of the sluices is about 0·002 to 0·013 of the surface of the chamber. Formerly the sluice-valves used to be executed upon the gates themselves, and the whole was in

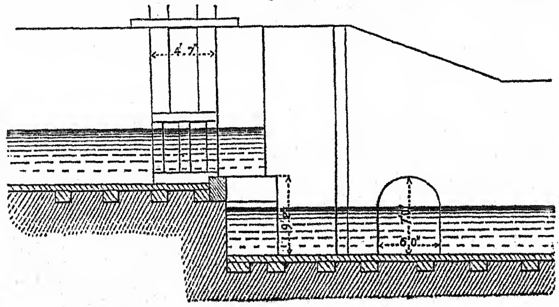
wood. This was found to augment the thickness of the gates to be lodged in the side-walls to an inconvenient extent, and latterly both the gates and their frames have been executed in metal.

The valves upon the gates should close hermetically, and be easily manageable; they must be as large as possible, to allow of the locks being filled in the shortest possible time, especially during the latter stages of the operation. To fulfil these conditions they must be about 4 feet wide, by from 1 foot 4 inches to 1 foot 8 inches high. In the latest works of this description, whenever the raking brace is suppressed, the whole space between the posts is devoted to the opening of the valves. On the Canal du Centre, in France, it was noticed that the water rose 8 feet in 6 minutes, and the last 8 inches alone took 4 minutes more. To remedy this loss of time, on the Canal St. Quentin a folding leaf of 1 foot wide was adapted to the top of the gate, and with tolerable success. But the lock-men in practice expedite the operations by opening the gates when the difference of level is about 6 inches: to do this in a manner not likely to injure the gates, the chord by which they are opened must be fixed at ⅓ of the height.

The orifice of the vanes must be placed as nearly as possible in the centre of the leaves of the gates, in order that the jets may meet and destroy their reciprocal effects. They are opened either by a rack and pinion, by an endless screw, or by a long lever. Frequently they are made with a counterpoise, to diminish the friction. The sluice-valves are always placed on the upper side of the gates.

Many instances occur in which the water passes through tunnels from the upper to the lower level; but such a system is liable to the very serious objections of augmenting considerably the quantity of masonry in the first case, requiring more expensive machinery in the second, and finally in being much more likely to get out of order. In fact, the abrupt curves which are necessarily made in such tunnels serve to retain the water and any mud they hold in suspension, and thus cause the tunnel to be rapidly choked up; it is also very difficult to repair or clean them out. Figs. 32 and 33 represent the tunnels used on the Canal de Briare.

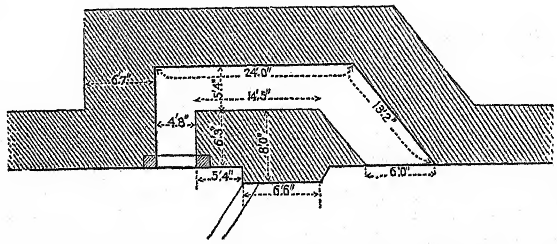
Fig. 32.



An inconvenience attached to this mode of changing the levels of the water in the lock-chamber arose from the fact that the two lateral streams, issuing from the tunnels, impressed an oscillatory movement upon the boats, causing them to strike alternately upon the side-walls. An attempt to remedy this was made by bringing the mouth of the tunnels under the breast-wall. But such a method, although it obviates the lateral shocks, is still objectionable, inasmuch as the strength of the breast-wall is much diminished. Practically, Engineers at the present day have

returned to the ancient system of sluice-valves upon the lock-gates themselves, as being the simplest and most economical.

Fig. 33.

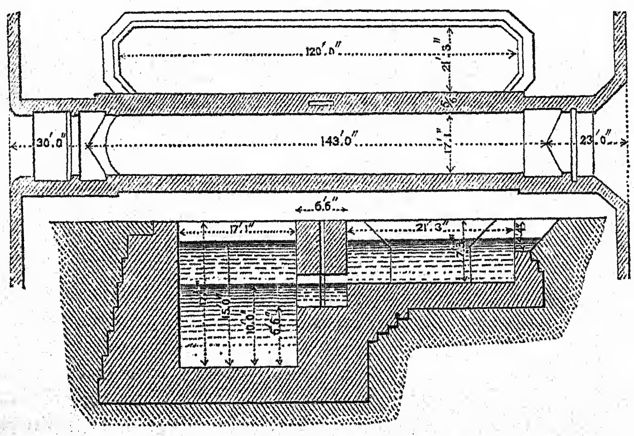


In proportioning the size of the opening of the sluices it must be borne in mind that the effective discharge from them is never equal to the theoretical discharge. Both from the contraction of the fluid vein in the first movements of the flow, and the diminished discharge owing to the smaller head of water at the end, it has been found that the results obtained from theory differ very much from those which occur in practice. When only one sluice is in operation, it appears that the real discharge is only 0·625 of that obtained from the elements furnished by the head of water and the surface of the opening. When two sluices are in operation the coefficient becomes 0·548. Or the quantity discharged through two sluice-gates, drawing water from the same source, and whose streams meet immediately after leaving the upper level, may be represented by the formula, $Q = m\,S\sqrt{2\,g\,H}$; in which m = the coefficient given above; S = the sectional area of the sluices; g = the numerical expression of gravity at the intended position of the lock; and H = the height of the head above the opening.

Accessory Works.

52. In constructing the locks it is desirable to provide mooring-posts at the ends, and towing-rings in the side-walls, to facilitate the movements of the boats. Sometimes ladders are let into the side-walls to allow of visiting and repairing the lower parts of the chambers. Provision of some kind, either by means of a rope stretched

Fig. 34.



Side-Pond on the Canal d'Antoing.

across the lock, or by a boom, must be made to prevent boats from striking against

the gates whilst waiting to be passed from one level to the other. The entries to the chambers must also be arranged in such a manner as to allow boats to be directed easily into them.

When the navigation is active it is necessary to have two locks side by side, one locking up whilst the other locks down. Such an arrangement enables a considerable economy to be effected in the consumption of water; for if an aqueduct be made between the two, all the water which passes from one to the other is, in fact, economized upon the quantity required from the upper level. In warm dry climates many systems have been introduced to save the water in lockage, an example of which from the Canal d'Antoing is given; but the construction of such works resolves itself at last into a simple question of economy. On the same canal a very admirable system was adopted, which may probably be found capable of more general applicability. It consisted in the establishment of a double steam-engine of 112 horses' collective power, which pumped up the water from the lower level of a series of five locks placed in juxta-position. The water thus passed down through the locks was made to serve a second time at an expense not exceeding 0·00228 of a penny per foot cube. Such a use of steam-power is not, however, cited as a novelty, for many of our own canals employed it largely. Telford appears to have arrived at the conclusion that the use of side-ponds rather lengthened the operations of lockage.

The opening of the gates sometimes necessitates the establishment of some machinery upon the platform of the locks, especially when their dimensions are considerable. Small locks are opened either by means of a lever formed by the prolongation of the top rail, or by pushing or pulling the gates with a kind of boat hook. Larger ones require to be moved by a rope or chain working upon a barrel set in movement by a wheel and pinion.

The communication between the two sides of the platforms of a lock-chamber is usually effected by means of a footpath carried upon the gates themselves, care being taken that no projection be left towards the chamber to interfere with the movements of the boats.

Telford describes a system employed on the Shrewsbury Canal, which may be advantageous in cases where small or short boats are in general use. It consists in so forming the locks as to admit either one, three, or four boats to pass at a time, without the loss of any more water than what is just necessary to regulate the ascent and descent of the boat or boats that are then in the locks. This is accomplished by having gates that are drawn up and let down perpendicularly, instead of being worked horizontally, each lock having three gates.

Substitutes for Locks.

53. In some situations it has been found necessary to adopt a different method of passing boats from the higher to the lower level of a canal than by the use of locks. Such a necessity may arise from a want of water, or from the fact of the natural form of the ground being so abrupt as to make the number, or the fall of the locks, inconvenient. The different means of effecting the object in question have varied in an infinite degree, but they may be conveniently classified under two heads, viz. balance-locks, or inclined planes.

Telford mentions several descriptions of balance-locks proposed from time to time, for details of which the reader is referred to the 'Repertory of Inventions,' vols. i. ii. and ix., and to Chapman's 'Observations on Canal Navigation.' On the Grand Western Canal a balance-lock of this nature has been executed, by which a difference of level of 46 feet is compensated with a remarkable saving of time and water. It

consists of two chambers, with a pier of masonry between them, of the dimensions necessary to receive a case into which the boats are floated. Strong chains pass over a series of wheels supporting the cases, working in the chamber in such a manner that one is kept upon the upper level whilst the other corresponds with the lower one. The quantity of water admitted into the upper case is so arranged as to give it a slight preponderance over that of the lower, sufficient to impress a gradual and easily regulated movement to the machinery. The passage from one level to the other does not occupy more than three minutes, and the consumption of water is about two-thirds of what would be required to fill a lock of the same dimension. The only objection to such a system is its expense, and the difficulty of maintaining it in working condition.

Inclined planes have long been in use, and offer great facilities for overcoming differences of level, when these pass certain limits. In all these cases it is important not to lose sight of the fact, that the applicability of such substitutes for locks is an economical question, in which it is necessary not only to consider the cost of the first establishment, but also that of the working and maintenance. Unless, therefore, the difference of level be very great, there can be no advantage in departing from the ancient system of locks.

Pont Aux Rouleaux.

54. Telford mentions the construction of a 'pont aux rouleaux' on a canal near Saarndam; this consisted of a set of rollers placed at short distances, over which, by means of a water-wheel, the boats were hove up to the ridge separating the two waters to a point a little higher than the level of the upper one, and were launched down to the other.

Inclined Planes.

55. On the Duke of Bridgewater's subterranean canals one inclined plane was formed $35\frac{1}{2}$ yards high and 151 yards long: the water escaping from the upper chamber in this case served to work the air-pumps of the lower level of the mines. On the Shropshire canal there are three inclined planes, respectively of 126, 120, and 207 feet rise, which were completed in the year 1792. The boats are adapted to frames upon carriages made to run upon railroads, and they are set in motion by a steam engine acting upon an endless rope coiled upon a drum. On one of these inclines, 600 yards in length and 42 yards rise, six boats were taken up and six taken down in an hour, the steam engine and three men only being employed. The boats were only of 5 tons each. On the Shrewsbury Canal, Telford executed a plane 223 yards long and 25 yards rise on the same principle.

On the Canal du Centre similar inclined planes have been introduced, on account of the want of water. On the Morris Canal, in the United States, there are no less than fourteen such planes, each about 100 to 102 feet high, with an inclination of 4 feet base to 1 foot in height. M. Bétancourt indicates as the limits of inclination a range between 8° and 25°, or from 7 to 46 in 100.

On the Duke of Bridgewater's Canal the consumption of water for the passage of a boat is only equal to about one-half a lockful, whilst the ordinary system would have required no less than from 28 to 30 times that quantity. The boats are run into a lock at either extremity, and the whole case traverses the inclined plane to the lower level, where the boat floats into the ordinary part of the canal. On the Shropshire inclines they are simply let into carriages, which are subsequently carried over a summit closing the end of the canal, and then let down into it. On the Morris Canal the locks themselves traverse the planes, so as to maintain the boats constantly floating during the passage. Each lock is 50 feet long, 9 feet wide, and 3 feet deep, and contains 45 tons. It rests upon a triangular frame running upon rollers, weighing, with the empty lock, 15 tons, or 60 tons when full. The boats usually weigh, loaded, 25 tons. The cost of the construction of this series of planes

upon the Morris Canal was only half that requisite for a set of locks able to produce the same result, as far as compensating the difference of level is concerned: the economy of water is therefore a pure gain.

Over-Bridges.

56. When it is necessary to erect bridges over canals, the height from the water-line to the under side of the arch should not be less than 13 feet, if the locks are 17 feet in width. If constructed to receive large boats, and the locks are 26 feet in width, it is preferable to augment the height to 18 feet. The water-way should be from 1 foot 4 inches to 2 feet wider than in locks, for boats do not stop to pass through them, as in the latter case. A bridge should be placed in such a position that the canal should be in a straight line above and below it for about 200 or 300 yards.

On the Dutch and Belgian canals it has been found necessary to execute many swivel or lifting bridges, to carry roads over the canals. Such erections are very costly, and they entail considerable expense for maintenance and management. If therefore they can be avoided, and permanent works substituted for them, it is very desirable. The rules which regulate the construction of canal-bridges are equally applicable to all similar works: the reader is therefore referred to the articles 'Bridges,' and 'Passage of Rivers.'

Culverts and Aqueduct Bridges.

57. In traversing a line of country of any length, especially in mountainous regions, streams holding much foreign matter in suspension are frequently to be diverted, so as not to discharge their waters into the canal. Such streams may be encountered at different levels, either above or below the water-line of the canal, requiring a different system of construction in either case.

If the level of the stream be much above that of the canal, the simplest mode of dealing with it is to carry the aqueduct at once at the higher level. But such a case rarely occurs, and the streams mostly are but little removed from the level of the canal, rendering necessary the construction of a syphon or a straight culvert. Such culverts are simple enough; but the syphons are difficult to repair, and they very soon choke up if the waters brought down by the stream be at all troubled. They should only be used for very limpid waters, and settling reservoirs should be formed before the entry of the syphons.

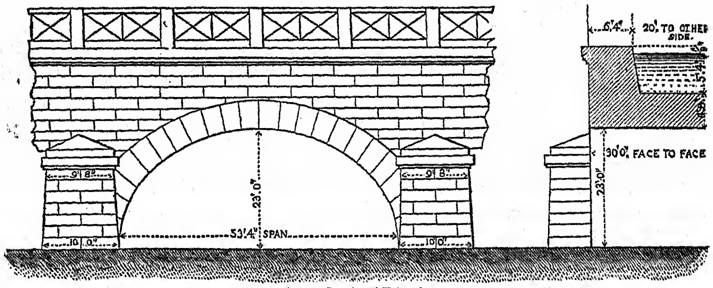
When, however, the stream assumes any considerable dimensions, it is necessary to carry the canal over it by a bridge, the form, nature, and expense of which depend on the size of the river to be traversed. Such a bridge, in addition to the ordinary difficulties attending the construction of similar works, becomes more difficult from the necessity of rendering it water-tight. Leakages, in fact, compromise the solidity of the works in the same proportion as they entail a loss upon the water in the canal. For small bridges this object may be effected by lining the bottom of the bed with lead or zinc; for larger works such a course is not applicable, and the bridge itself must be made to retain the water.

The width of the water-way in a bridge aqueduct need not be more than 8 inches on each side than the widest boats likely to traverse it, or, in fact, a little more than that of the locks upon the same canal. Only one towing-path is absolutely necessary, although it is usual to execute two: if for men, 3 feet is sufficient; if for horses, they should be 6 feet wide.

When the bridge is executed in masonry, the actual bed of the canal should not be constructed until the centres have been struck, and all settlements have taken their

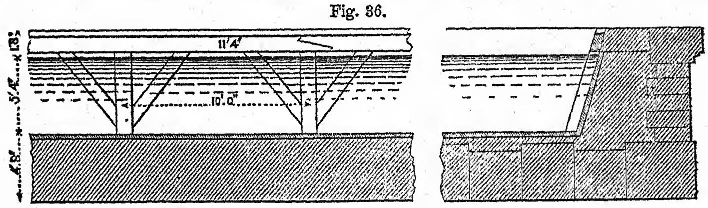
full effect. The bed should be executed in concrete, made very carefully with the best hydraulic lime; and it is a very necessary precaution to form, in the haunches of the arches, aqueducts to carry off the waters which might filter through. When the bed is executed in masonry, care must be taken to coat the intrados of the arches with either asphalt or concrete, and the inside of the masonry must be pointed and

Fig. 35.



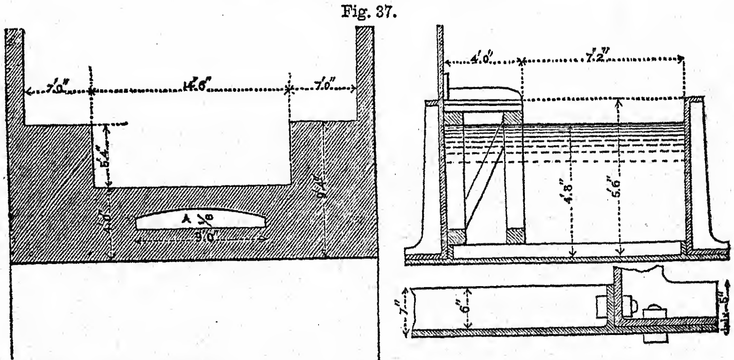
Aqueduct of Digoin.

Fig. 36.



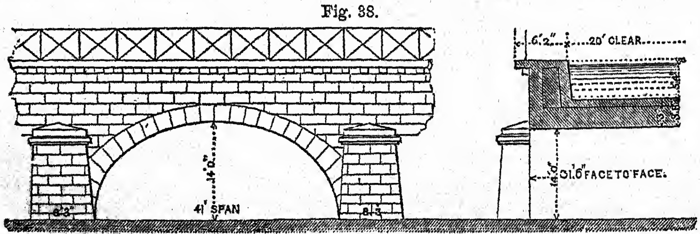
Trough showing timber-guards, Digoin.

Fig. 37.



Union Canal, Scotland.—A, warm-air flue. Cast-Iron Aqueduct, Ellesmere Canal.

Fig. 38.



Aqueduct de la Bêbre.

rendered with hydraulic cement. The water must be introduced as soon as possible, in order to prevent fissures from the sudden drying of the lining.

58. The aqueducts of Digoin and of the Allier, executed under the orders of M. Julien, are perhaps the most carefully executed works of this description erected of late years. That of Digoin is 810 feet long, and consists of eleven arches; that over the Allier is 1298 feet long, with eighteen arches, and three locks comprised in the prolongation of the wing-wall on the down side. The first aqueduct cost about £192 per metre, or £172 per yard; the second cost £296 per metre, or £266 per yard.

On the aqueduct for the Union Canal in Scotland, a warm-air flue was introduced to prevent the injurious effect of the frost. (See fig. 37.)

On the Ellesmere and Chester Canal, Telford constructed one of the most remarkable and original works which he ever executed, to carry the canal over the valley of the Dee. It consists of an aqueduct 1007 feet in length by a maximum height of 127 feet. The piers are about 45 feet apart from centre to centre, by 7 feet 6 inches wide, and 13 feet broad at the top. The trough is formed of cast-iron plates, supported upon four cast-iron arched beams of 7 feet 6 inches chord to the intrados, well cross-braced and tied together. The towing-path is supported in such a manner as to allow the water to flow freely under it. The side and bottom plates are firmly bolted and riveted together. The total expense of this truly wonderful work was £47,018, or about £141 per yard; and considering the boldness of its conception, the skill with which its details were carried out, and its moderate cost, the superior attainments of this eminent Engineer must be admitted.

In the United States, where wood is cheap, and masonry and iron-work excessively dear, aqueducts have been executed in carpentry. The most remarkable work of this kind is that which carries the Canal of Alexandria across the Potomac at Georgetown. It is about 1077 feet long between the abutments, and has nine arches. The piers are about 7 feet 2 inches wide at top, with a batter of $\frac{1}{12}$th on each side, and they receive the trough at a height of about 29 feet above high-water mark. Three of the piers, however, are of an extra width, so as to form intermediate abutments; they are made 12 feet 10 inches wide at the top. The length of the ordinary piers is 41 feet at the summit; measured upon the cut-water, at high-tide level, they are 47 feet 6 inches. The trough was executed in wood-work, upon Town's system, with double lattice on each side, 18 feet 8 inches deep. (See Plate V.)

The most extraordinary canal aqueducts hitherto executed are, however, those lately erected upon the irrigation canals of India, by Colonels Cantley and Baird Smith, Lieut. Haig, and the officers of the Indian army. Thus the Gunnarum Aqueduct over the Godavery is 2248 feet long, and has 49 arches of 40 feet clear water-way; the Solani Aqueduct is 750 feet long, it has 17 arches with 50 feet clear water-way, and a transverse section of not less than 1700 superficial feet in the water-way of the canal itself.

There are numerous inconveniences attached to the erection of bridge aqueducts, which should lead the Engineer to prefer carrying the canal in embankment, even at an increased expense, if there be no insurmountable difficulty in so doing. The diminution in the width of the canal renders the traction more difficult: much time is lost by the boats being forced to wait their turn; the maintenance is always a source of great outlay; and, lastly, the great cost of such erections often leads to lowering the canal on one side to rise again on the other, in order to save the height of the piers. If, however, the erection of a bridge aqueduct be inevitable, it is necessary, in addition to the precautions already mentioned, to place waste-weirs above the entry, so that, in case of flood, water may not fall over the sides of the embankment.

Meeting a River on the same Level.

59. Many of the affluents of the rivers which run in the valleys whose direction a canal follows must occasionally cross it at the same level. If they be not diverted and passed under the canal, but made use of for its supply, care must be taken to form settling reservoirs, and a dam with proper sluices to regulate the quantity of water to be admitted, and to destroy the velocity it might have acquired in its natural flow.

When the stream is, however, sufficiently large to be navigable, it is necessary to construct such a system of locks as to be able to close either navigation which may not be required; the normal position of the locks being such as to maintain a constant level of water in the canal. The great danger to be feared in cases of this description is, that the streams may bring down foreign matter to choke the bed of the canal.

On the Canal du Midi an ingenious system for closing the bed of a torrent at the time of floods was introduced. It consists of a pontoon, one side of which is fixed vertically, and the opposite side is made with a hinge. At the time of floods this pontoon is floated to the mouth of the torrent, and the hinged side is let down, the vertical one forming a dam. When the floods are over, the side is raised and the pontoon floated away. It is maintained in its position by walls in masonry at the intersection of the stream with the canal.

An example of a canal meeting a navigable river is given in the Plates.

Supply Valves, Waste Weirs, and Supplementary Works.

60. The introduction of water into canals is effected by means of conduits, which are regulated by gates whose openings are proportioned to the wants of the navigation. The nature of these works varies so much with the nature of the supply of each particular canal, that no general rule can be laid down for their construction. They must of course be large enough to admit the flow of water with tolerable rapidity, in order to fill the canal with the least possible loss of time after it has been laid bare.

Waste-weirs must also be provided in each long reach of a canal, sometimes with a channel to lead the surplus water into the natural discharge of the surrounding country. In other cases the surplus water may be allowed to fall over the lock-gate or be led by a tunnel to the lower level. Care must however be taken that no cataract be formed in positions likely to injure the solidity of the works, and that the waters be not allowed to have a dangerous velocity at their place of discharge. Mr. Thom introduced upon the conduits leading water to Greenock several systems of self-regulating sluices, which might be advantageously applied upon canals.

Safety-gates have been occasionally used, which serve to close the canal when a current is formed in any particular direction by a fissure of any kind. They are, however, of doubtful utility, for they hardly ever act efficiently in cases of need.

Outfalls must be provided in each long reach of canal, to allow of its being laid dry for repairs or examination. Indeed, as this suspension of the navigation must take place once a year on account of the deposit of mud, or the development of the aquatic plants, it is important that it should be effected with the least possible loss of time.

Junction with Rivers, and Termini.

61. The termination of a canal in a river usually requires a double lock to maintain the level of the waters, either against the upper or under stream, especially when the embouchure is partly exposed to tidal action. It is advisable that such

locks be preceded by a basin or dock of sufficient dimensions to allow sea-going vessels to enter simultaneously with barges; and in such cases it is usual to provide a set of lock-gates to close the end of the canal which joins the basin. An excellent example of such a basin exists at the terminus of the Regent's Canal.

In ordinary cases the entry into a river must be placed on the concave bank, to avoid the destructive action of the stream; but as deposits take place on the concave sides, means must be provided to scour the passage to the locks. The entry must be above any affluent which might be in the neighbourhood; and its direction should form an acute angle with the stream of the main river, as was observed under the head of 'River Navigation.' The upper jetty should project into the stream so as to render the water in the entry perfectly still; the lower one should join the bank with an easy curve. Mooring-posts and guard-booms should be provided at the entries, to facilitate the movement of the boats, and to guard the lock-gates from the shocks of the vessels.

The first lock should be placed, at least, one clear boat's length from the extremity of the normal line of the bank on the up-stream side. Basins must be formed both at the termini and at the intermediate dépôts, and also such roads, sheds, machinery, and offices as the nature and importance of the navigation may require.

Fences and Enclosures, &c.

62. Lastly, it is necessary that a canal be carefully protected from injury by trespassers, or by the cattle in country districts, by means of strong and efficient fencing. Such fences should be backed by a hedge and ditch, for the double purpose of rendering the enclosure more perfect, and of carrying off the rain-water it is considered desirable not to direct into the canal. In the interior of towns, or upon the borders of a highly frequented road, it is often necessary to enclose a canal with a solid wall, or at least with a close-boarded fencing. Basins, or intermediate ports, are especially necessary in such positions as require perfect enclosure, both for the security of the canal itself and for that of the goods transported.

Dépôts must be formed, at convenient distances, of all the materials necessary for the maintenance and repairs of either the bed of the canal or of the works, including under that term locks, bridges, culverts, and aqueducts. It is advisable to have in such dépôts all the materials necessary to form a dam across the canal, in case it becomes requisite to execute on an emergency any repairs which would, without such a precaution, require the canal to be entirely laid dry. Materials for the repair of the towing-path must also be provided at convenient spots.

The dangers arising from the burrowing of moles and rats are so great that it is expedient to have a person specially charged to destroy those animals. But perhaps the best remedy would be to execute a concrete lining to the canal, instead of merely puddling it.

Constant superintendence on the part of the resident Engineer cannot be too much insisted upon. The embankments, cuttings, tunnels, locks, lock-gates, bridges, and culverts, are all exposed to injury; but a slight repair in the first instance would often save immense outlay in the end, and it is but bad economy to endeavour to dispense with skilful superintendence.

Statistics.

63. A statistical account of the canals in different countries would far exceed the limits of this article: the following statement will, however, indicate the commercial importance of the subject, and serve as a guide to the Engineer in forming approximative estimates of the cost of similar works.

In England, according to Mr. G. Rennie's Report to the British Association, in the years 1838 and 1839, no less than 2277 miles of canal navigation had been executed up to that period; in Scotland not much more than 200 miles; and in the whole island of Great Britain, 2236 miles of river navigation had been improved.

In the United States, up to the year 1837, more than 2000 miles of canal had been constructed, at an average cost of about £4600 per mile.

In France, to about the same period, according to the statistics communicated to Mr. G. Rennie, there was executed for the seven lines of junction between two seas a length of canal of 3,068,876 metres, at a cost of 306,429,601f. 50c. The length of the lines leading to Paris was 1,020,022^{m}·64, at a cost of 143,935,916 francs.

Maintenance.

64. The maintenance of the New York Canals cost, up to 1837, no less than £180 per mile; that of the Ohio canal, £64. On the French canals, the maintenance has varied from £60 to £87 per mile.

Detailed Costs.

65. It may be estimated with tolerable safety that the average cost of canals is about £4 per yard, with an addition of about £1000 per yard of the fall of lockage. Each lock on an ordinary canal costs about £3000. On the Caledonian Canal, where the locks are 170 feet long by 40 feet wide, and 8 feet fall, the cost was about £6000 per lock.

The waste weirs for a large canal cost about £1500 each.

Basins and dépôts on the intermediate parts of the line require an additional sum of about £1500 each. Those at the termini vary so greatly in importance that it is not possible to predicate their expense.

Common under-bridges, of not more than 30 feet span, cost about £500 each, on the average. Small over-bridges may be taken at the same price.

It is difficult to estimate the expense of large aqueducts; but as an approximation, it may be stated that some of the most expensive have cost as much as £2 per yard superficial of waterway, when they have been about 130 feet high.

Working and Tolls.

66. In the working of canals, the expense of loading and unloading the barges may be taken at from 7*d.* to 10*d.* per ton; and the traction and expenses of navigation, upon a well-managed canal, should not exceed 5*d.* per mile traversed by a boat. The tolls must necessarily vary with the number of locks and the first cost of the canal: they may, however, be assumed as being about the same as the traction, or 5*d.* per mile traversed.

The loss upon the goods transported, owing to the leakage of the boats, is sometimes as much as 1 per cent. on their value; and a similar allowance is commonly made for the pilfering to which the cargoes are exposed.

The principles which have guided the French Legislature in fixing the tolls to be taken by the Companies constructing canals in that country have been to allow a charge of 0^{f}·10 per ton and per kilometre, or 1^{d}·6 per ton per mile. Empty boats returning pay only 1*s.* per lock passed.

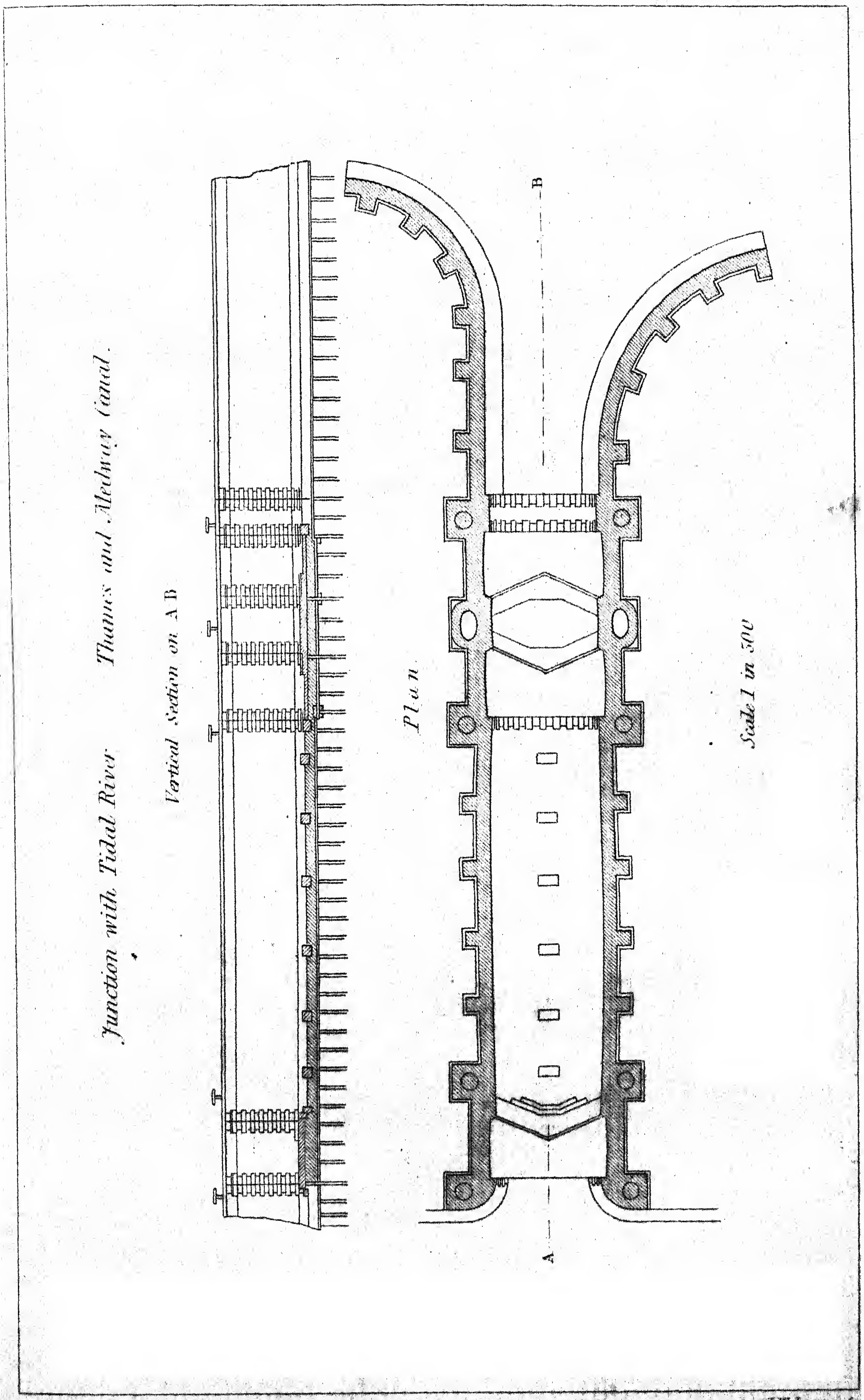
ROADS.*

PART I.—TRACING AND CONSTRUCTION.

SECTION I.—TRACING OF ROADS.

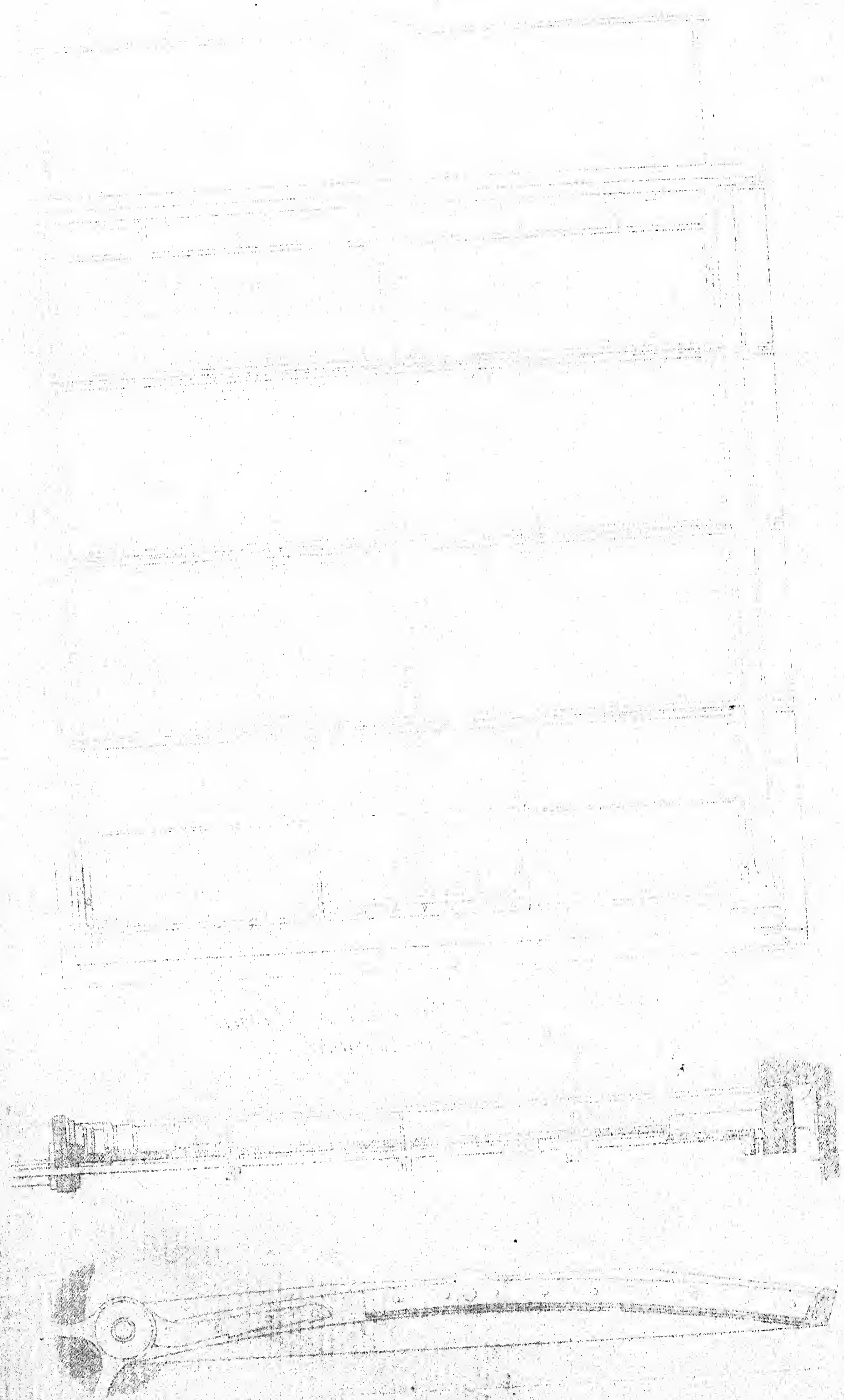
No surer indication can be afforded of the extent of a country's trade, or even of its advancement in civilization, than the existence of good and sufficient means of internal communication. For since it is one of the wise dispensations of Providence that many of those commodities which the present artificial state of society teaches us to regard as necessaries, are very unequally distributed, some being wanting in

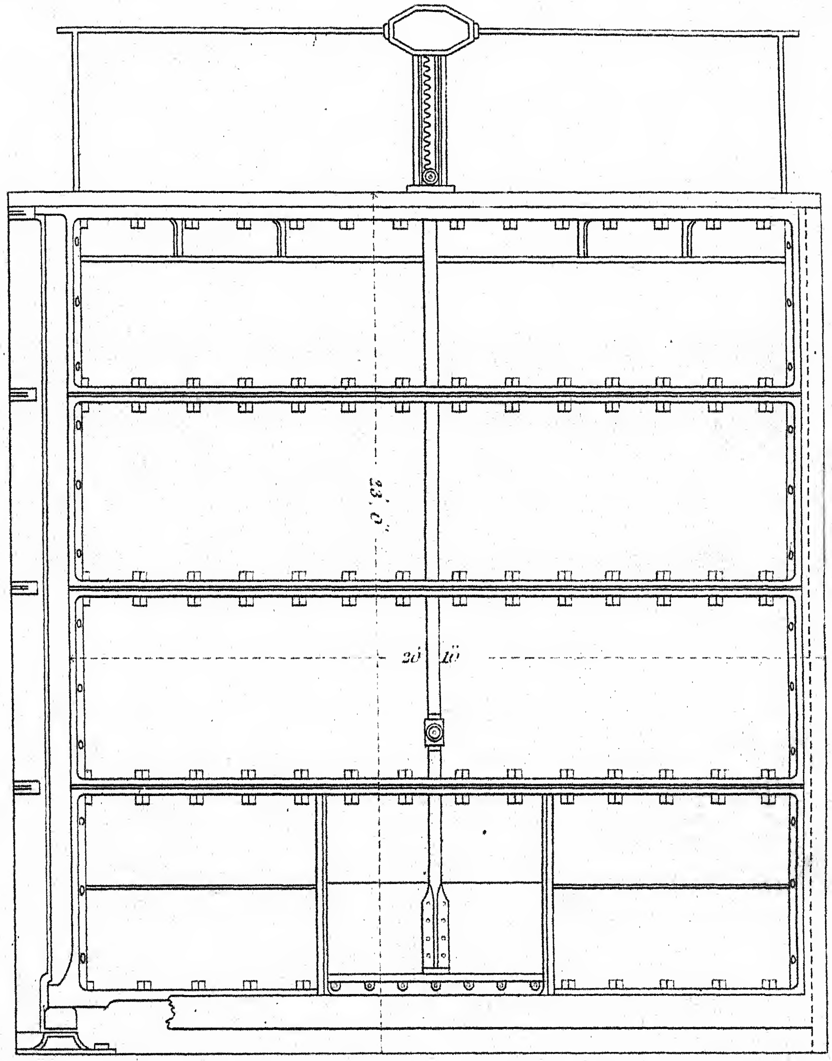
* By Henry Law, C.E



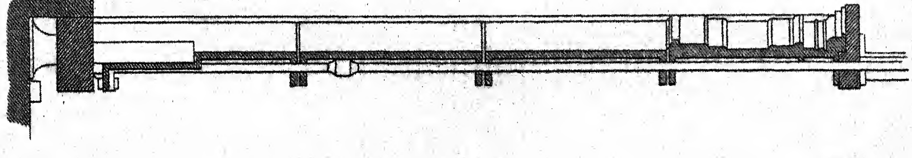
J. W. Lowry fc.

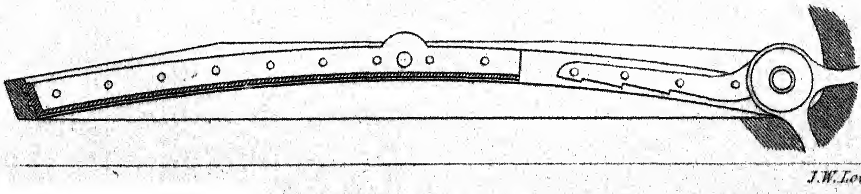
London, John Weale, 59, High Holborn, 1852.





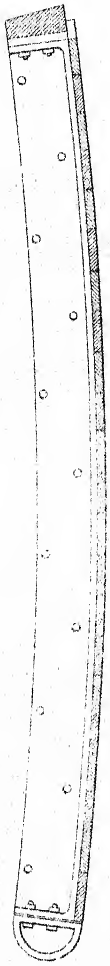
Cast Iron Gates of the Canal of St. Denis
Dept. de la Seine, France.

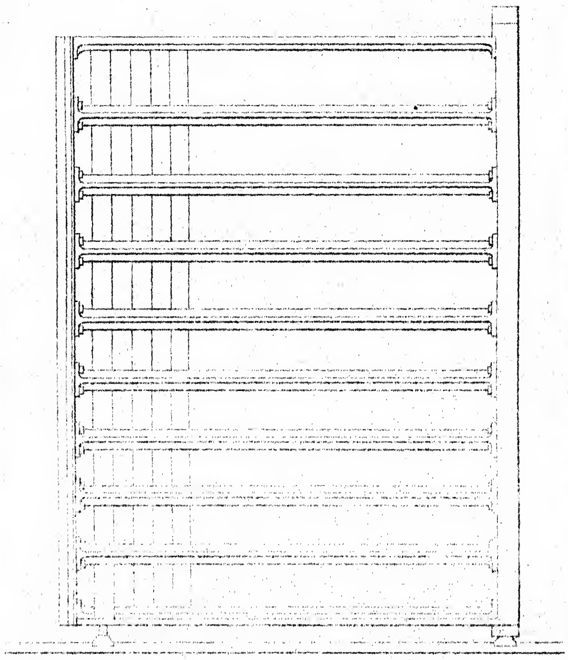


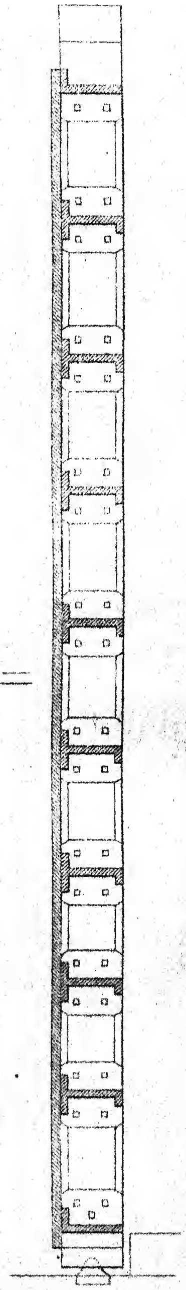


J.W. Lowry fc.

London. John Weale 59 High Holborn 1851.







Lock Gates of the

CALEDONIAN CANAL

of Cast Iron lined with Wood Planks

Scale of Elevation 1 in 100
Scale of Details 1 in 50

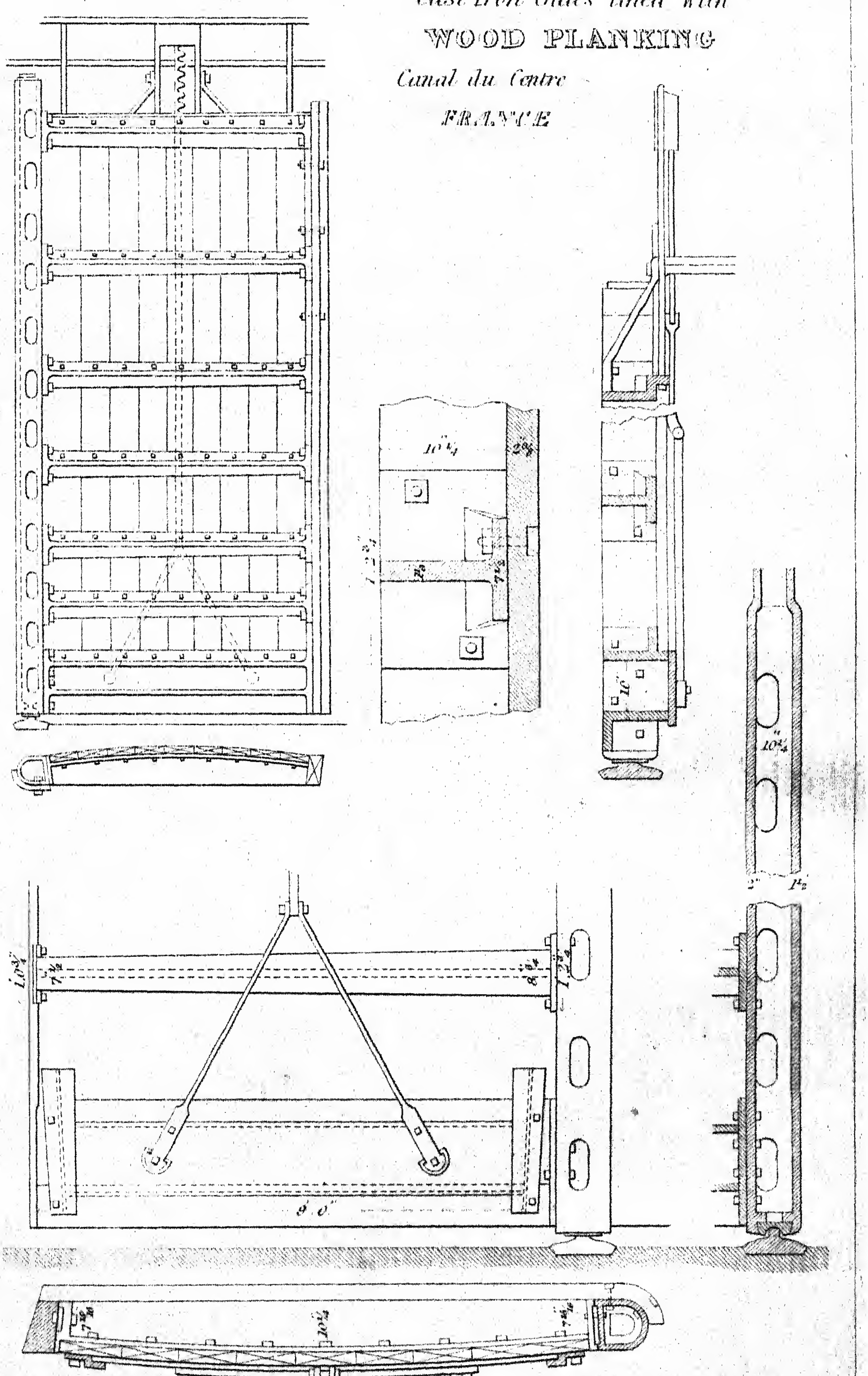
J.W. Lowry fc.

Cast Iron Gates lined with

WOOD PLANKING

Canal du Centre

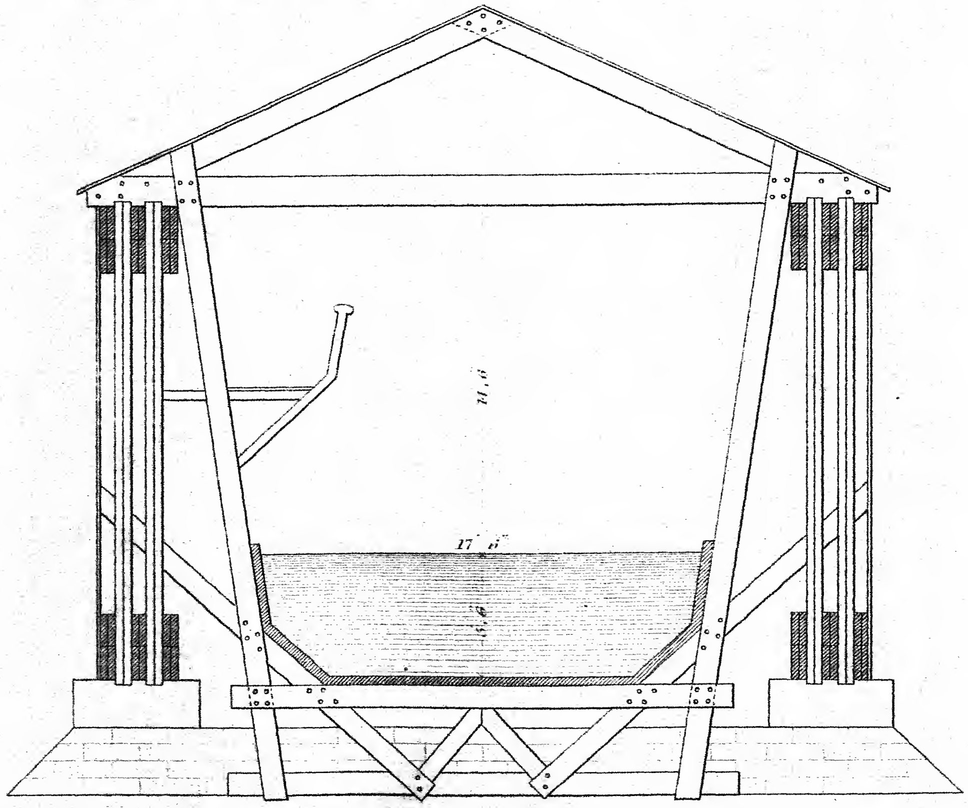
FRANCE



J. W. Lowry fc.

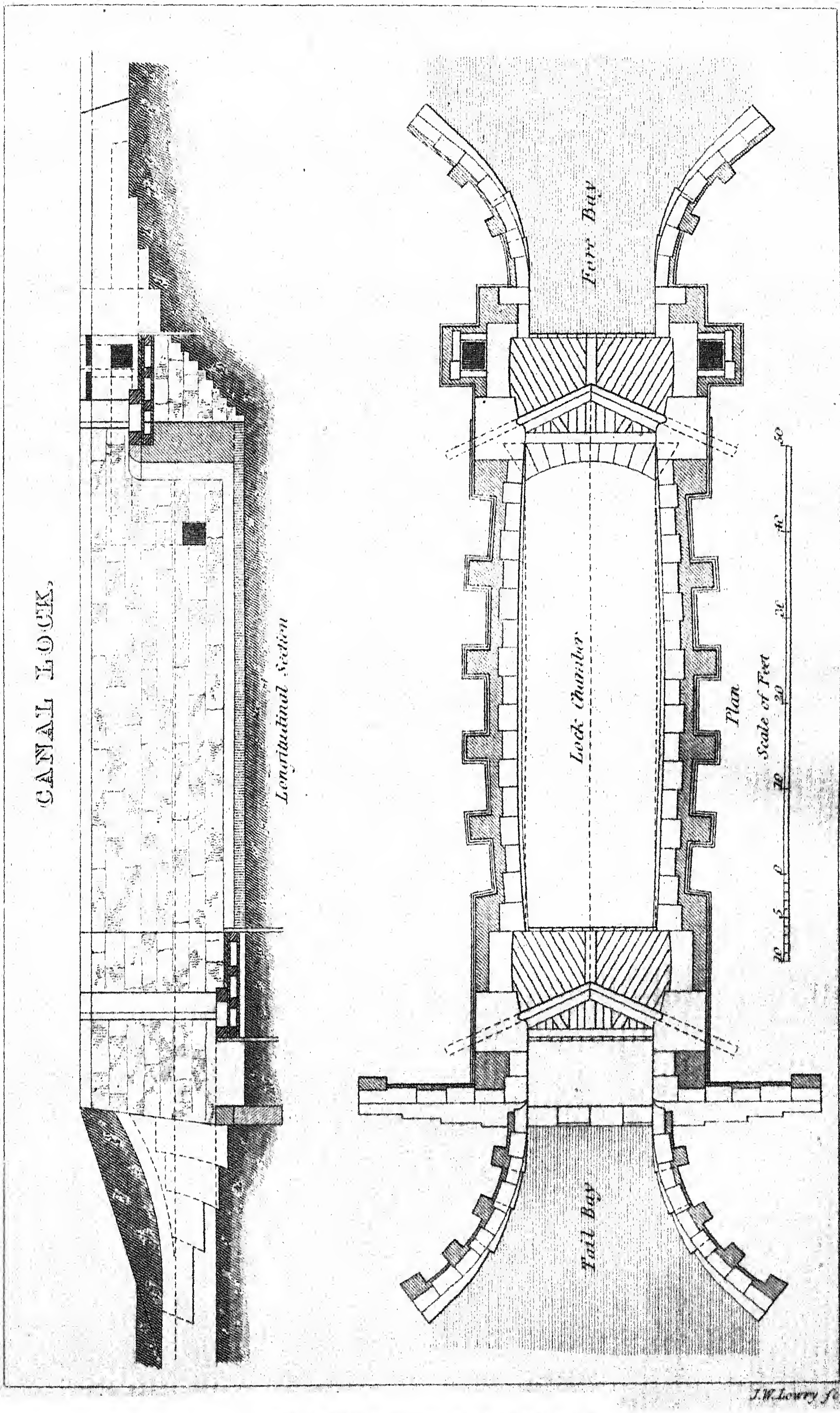
London: Lockwood & Co. 7 Stationers' Hall Court, Ludgate Hill, 1867.

Wooden Aqueduct over the Potomac Georgetown Columbia U.S.



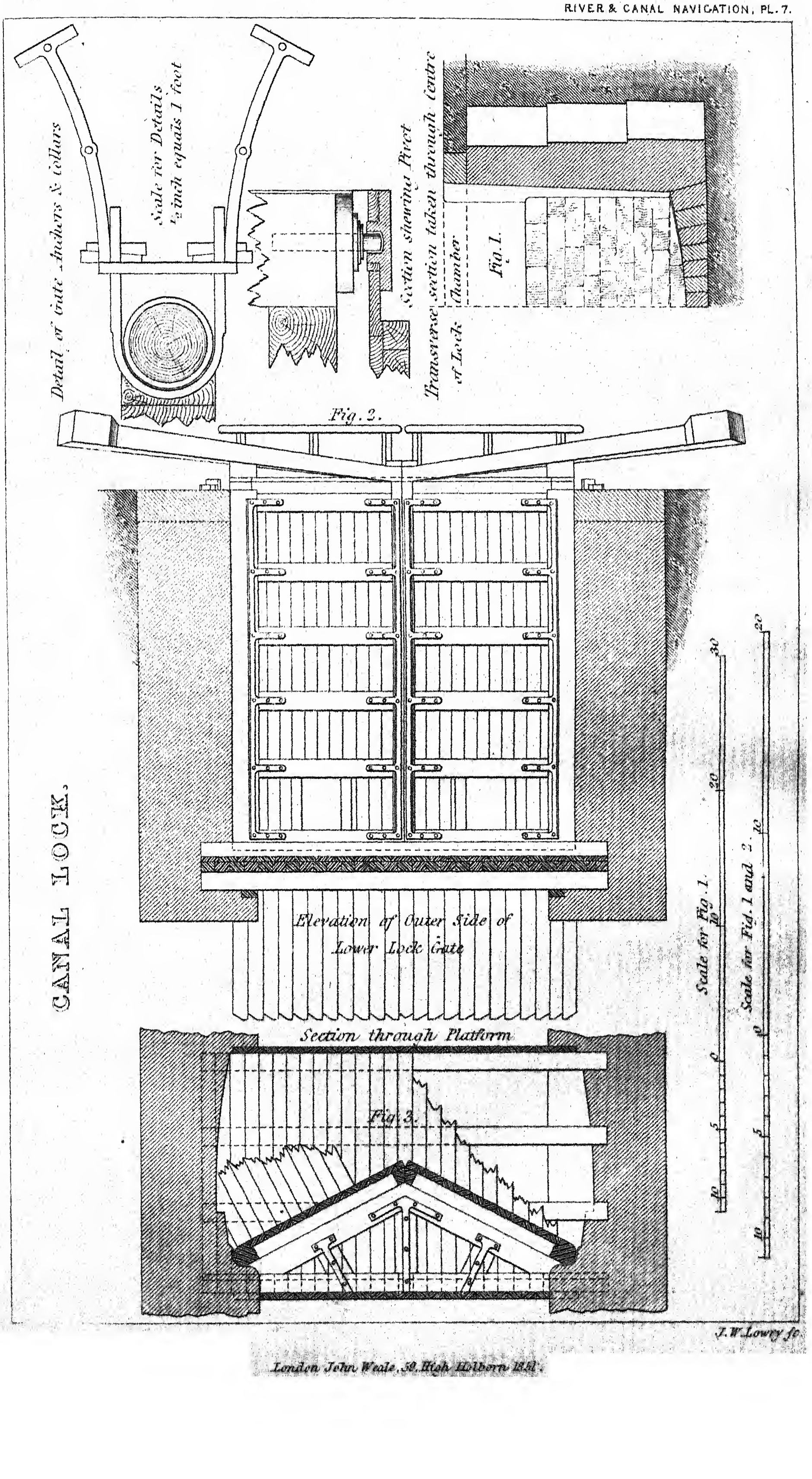
J. W. Lowry fc.

London, John Weale, 59, High Holborn, 1851.



J. W. Lowry fc.

London. John Weale. 59, High Holborn. 1851.

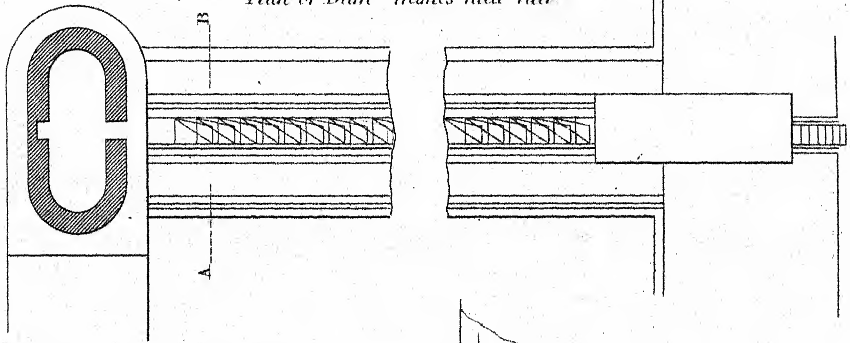


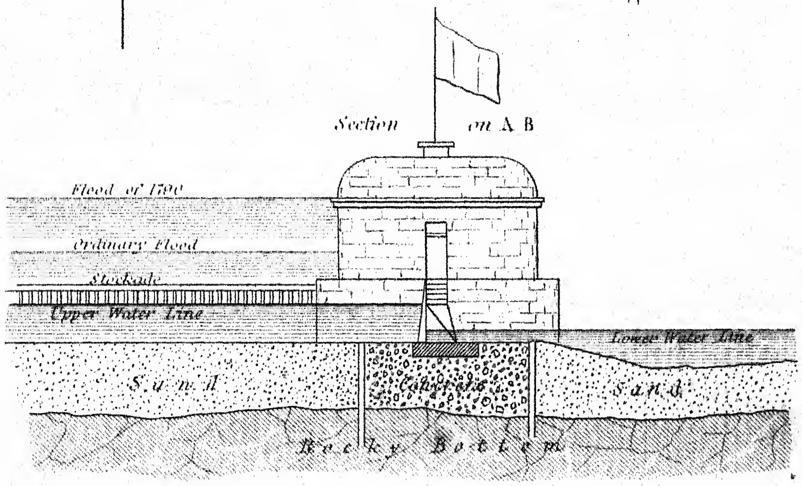
J.W. Lowry fc.

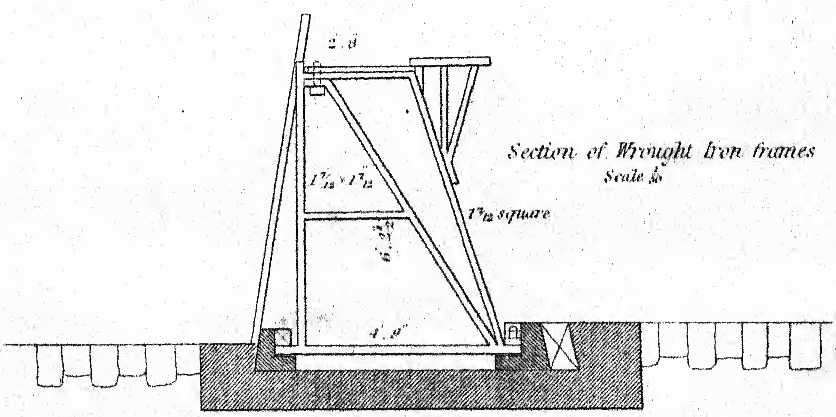
London John Weale, 59 High Holborn 1851.

Moveable Dam near Bezons, Department of the Seine No. 2.

Plan of Dam frames laid flat





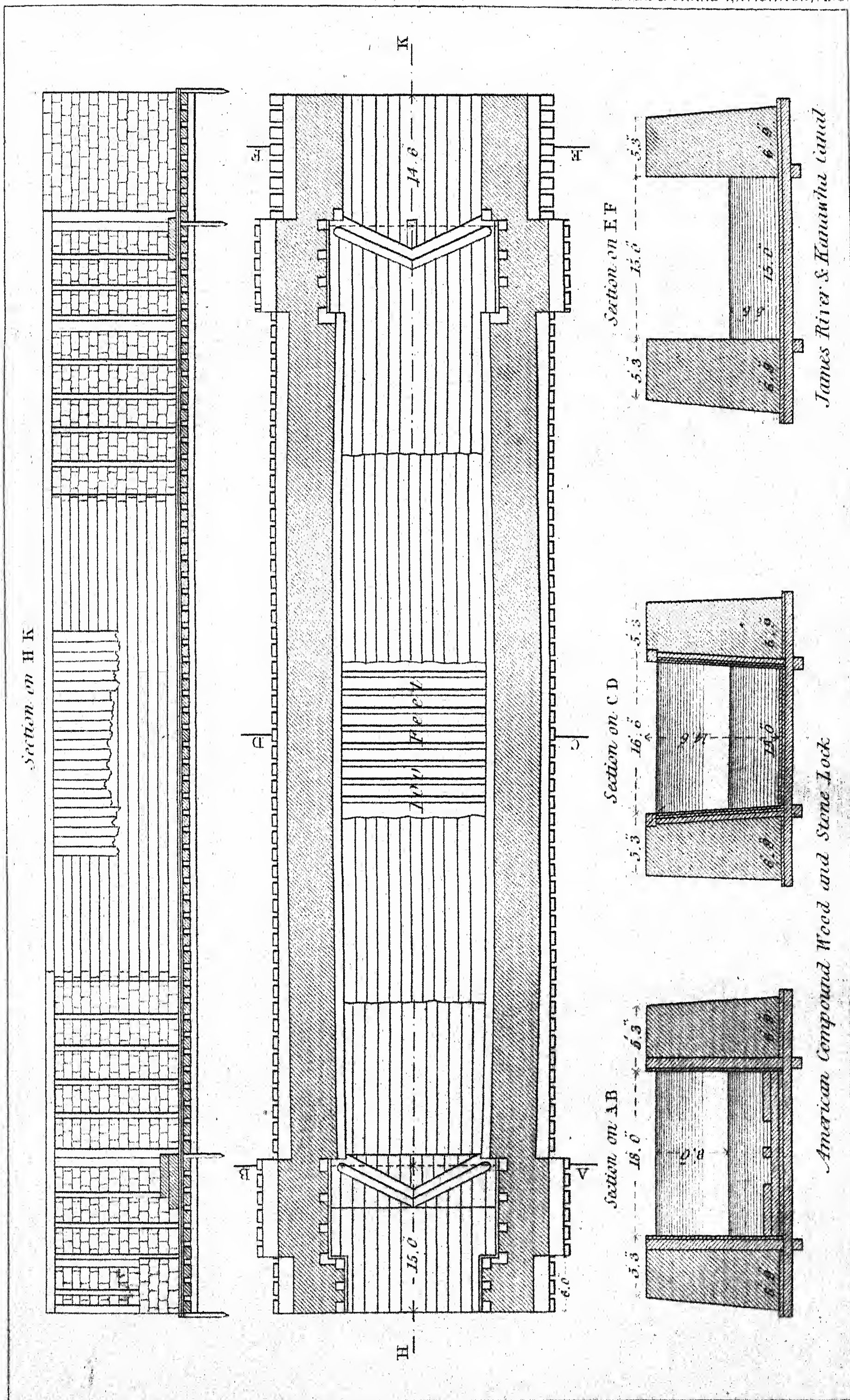


Section of Wrought Iron frames
Scale 1/30

Concrete filling paved on top

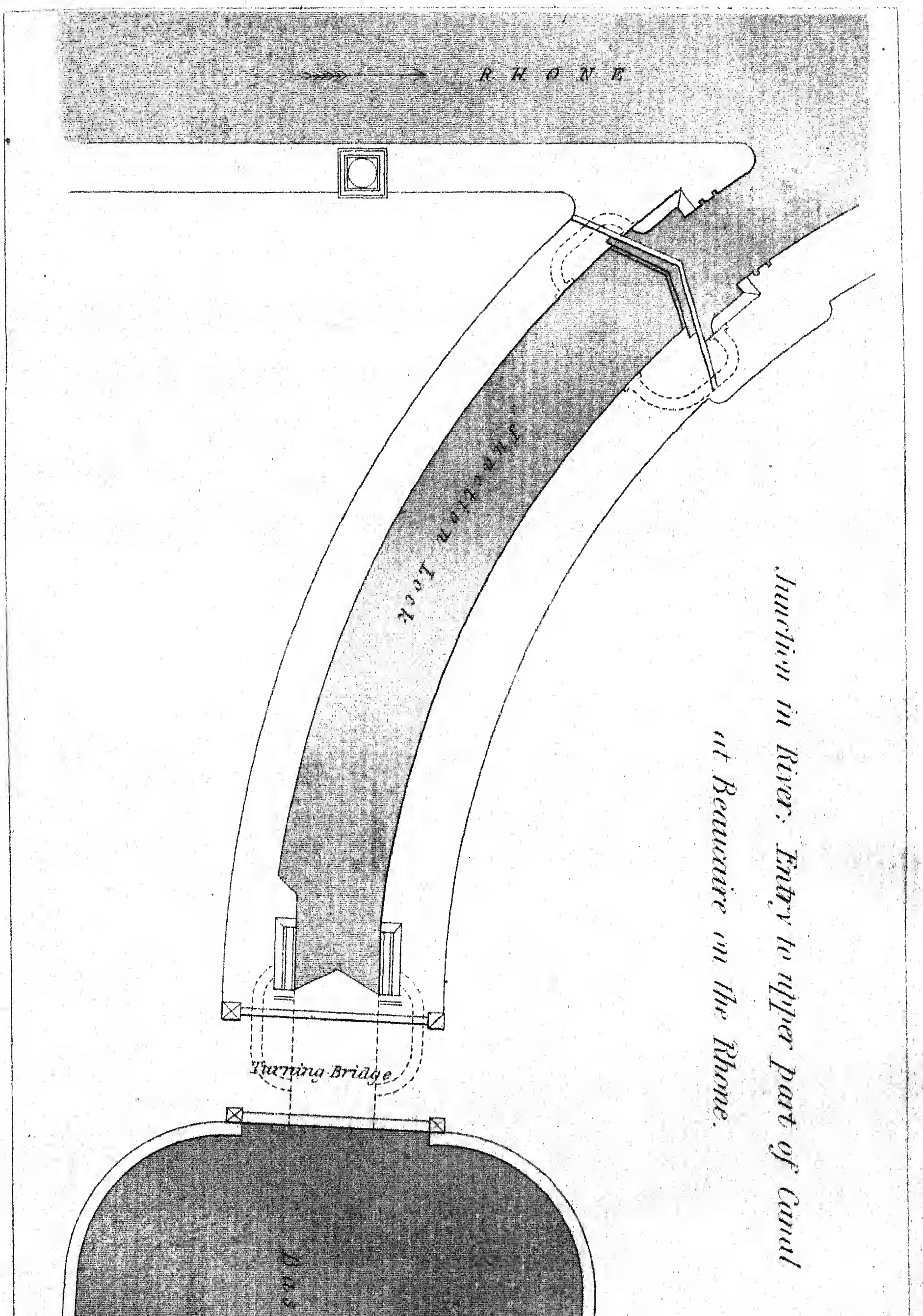
J.W. Lowry fc.

London, John Weale, 59 High Holborn, 1851.



J. W. Lowry fc

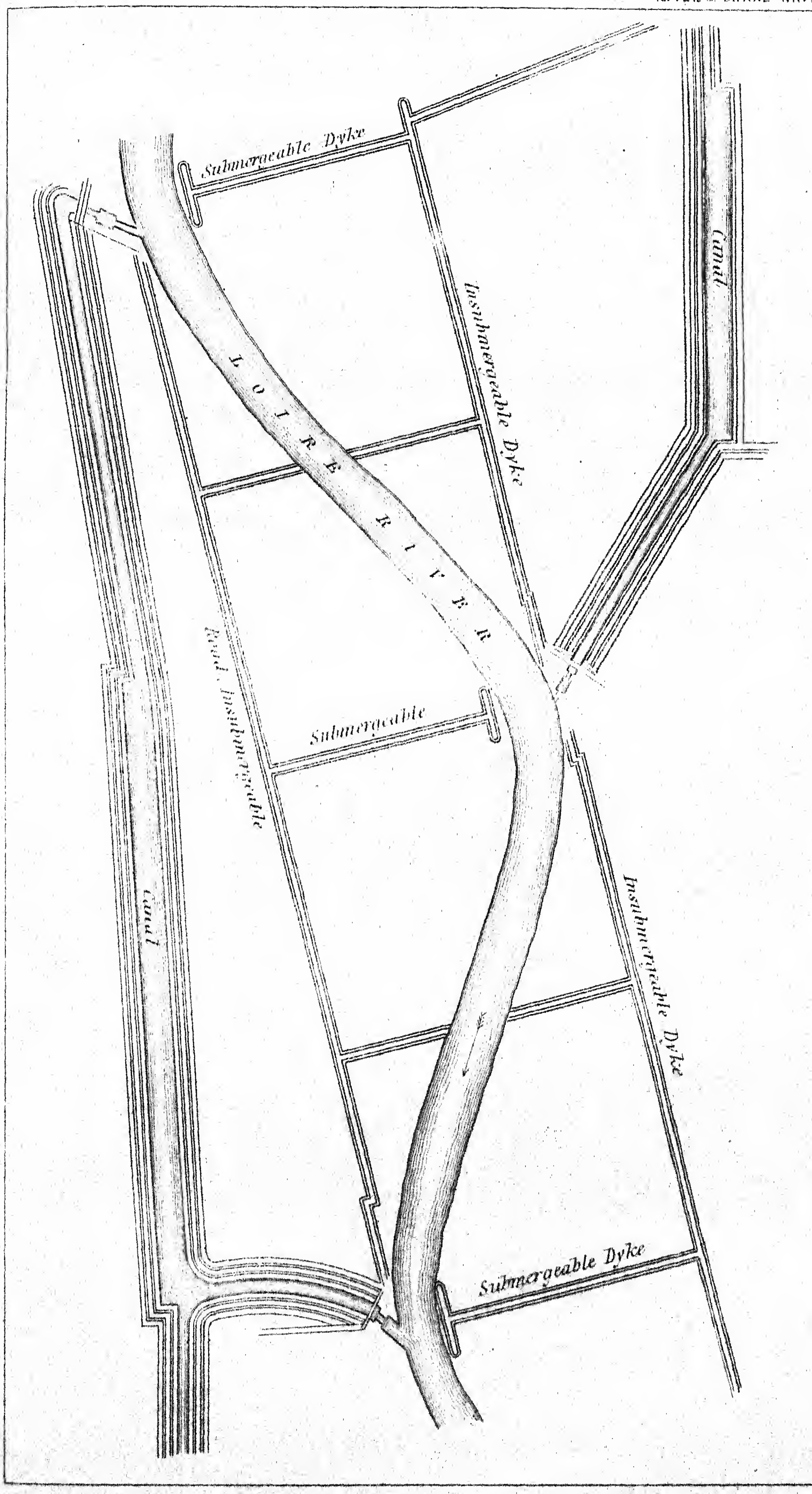
London, John Weale, 59, High Holborn, 1851.



Junction in River: Entry to upper part of Canal at Beaucaire on the Rhone.

J. W. Lowry, fc.

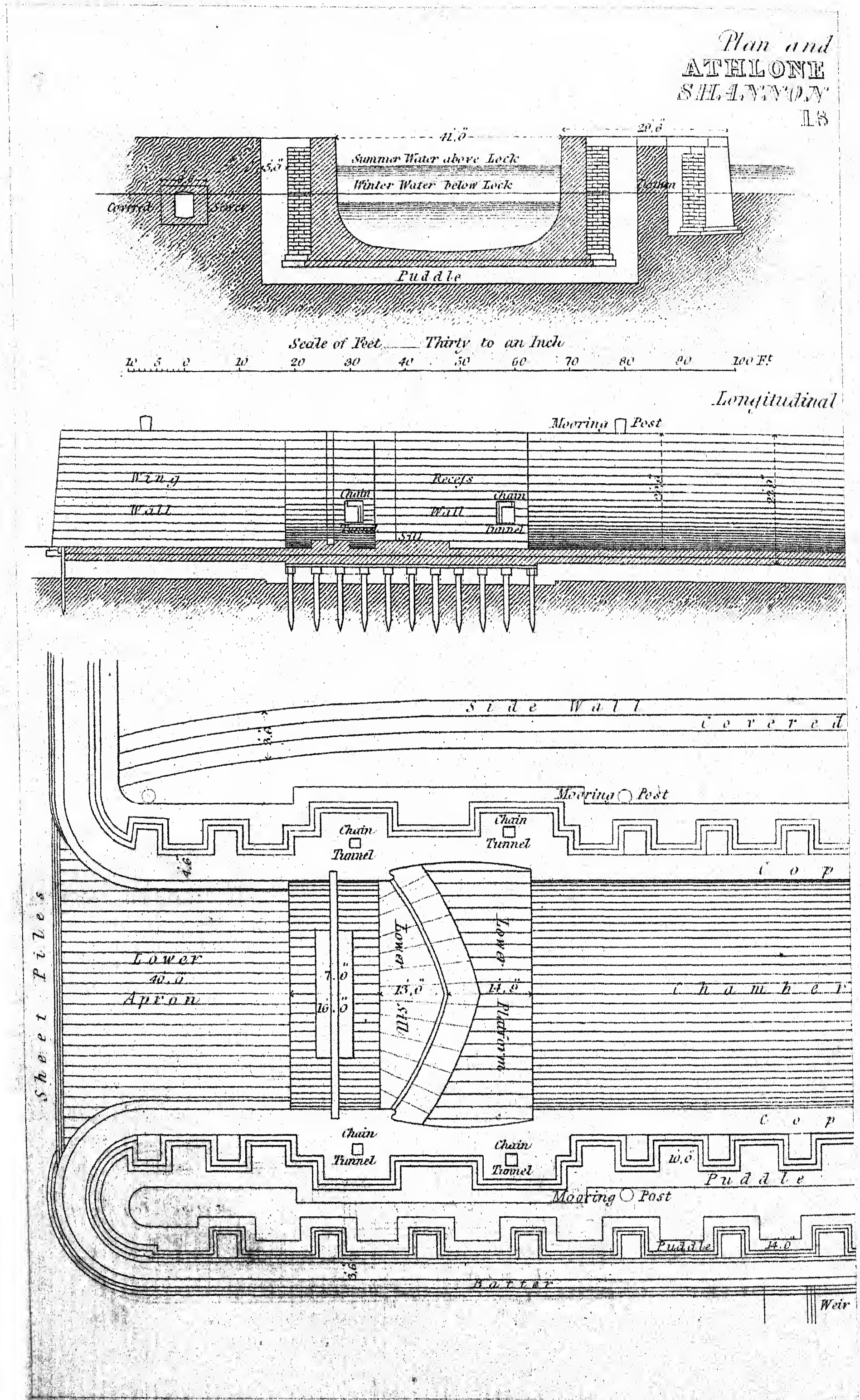
London, John Weale, 59, High Holborn, 1851.



*Example of a Passage from one Bank of a River to the other
Lateral Canal of the Loire. Châtillon sur Loire*

J. W. Lowry fc.

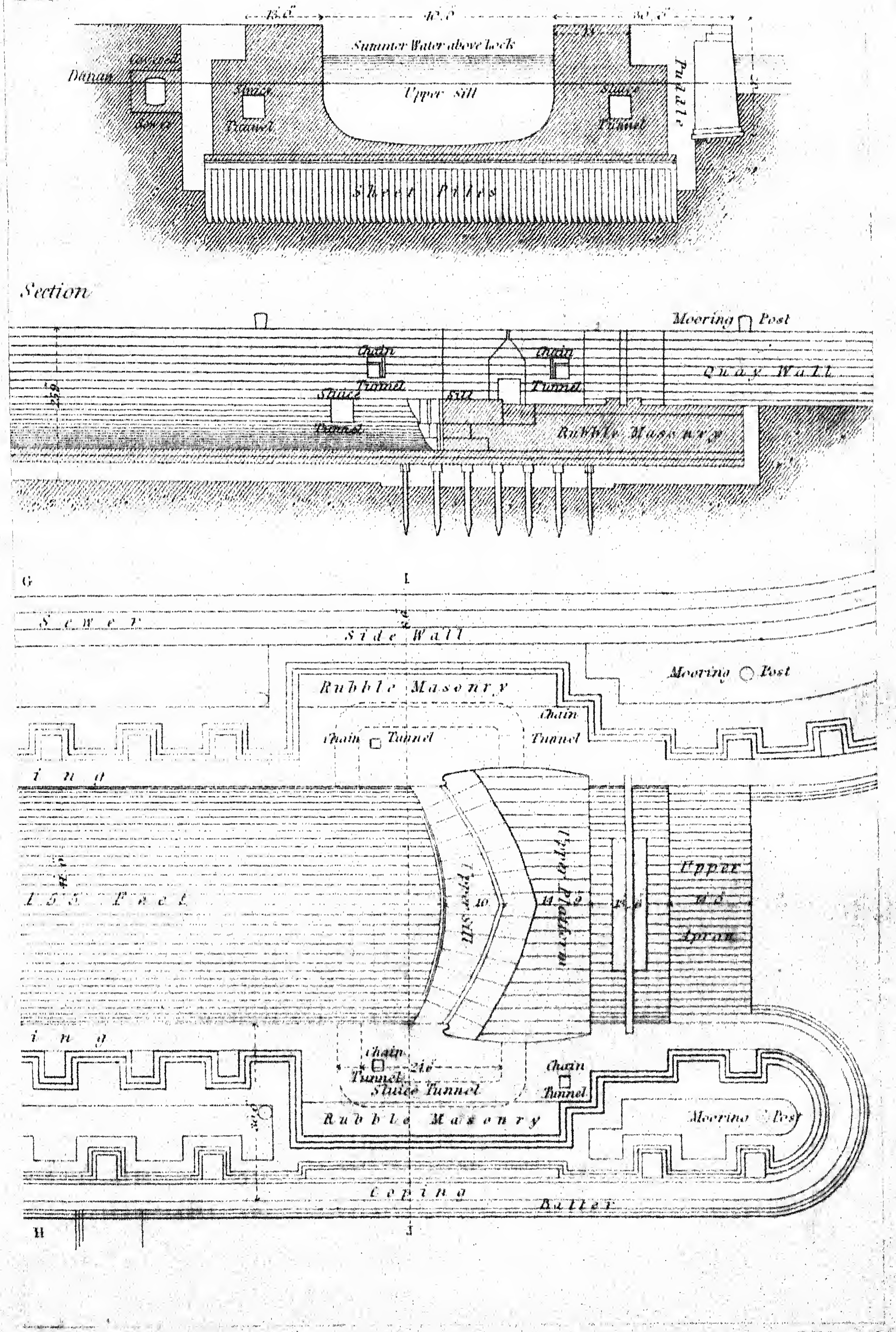
London. John Weale. 59. High Holborn 1851.



J. W. Lowry fc.

London, John Weale, 59 High Holborn, 1851.

Sections of
LOCK
NAVIGATION
48.



J.W. Lowry fc.

London, John Weale 59 High Holborn 1851.

certain localities where again others are only found, it becomes necessary, in order that all may be equally well served, that an interchange of these commodities should take place, so that the whole country may participate equally in the enjoyment and use of those things which would otherwise be confined to only certain districts. Thus, we may have in one part of a country huge forests, stocked with various kinds of timber; in another extensive tracts of fertile land, capable, if properly cultivated, of yielding supplies of corn and other produce, sufficient for the support of a densely-populated country; in a third mineral treasures, coal and iron, or the more precious metals; in another stone, well adapted for the construction of houses, and for other building purposes: and yet, with all these latent treasures dispersed throughout the country, of what avail would they be, unless the means were possessed of conveying them to every part of the land, and thus distributing to all what would otherwise be enjoyed but by few?

It is not, however, only for the purposes of its own internal trade that good means of communication are required: they become even more necessary, to insure an extensive commerce with foreign countries, to enable the peculiar produce of the several districts to be brought together to those parts of the coast which have been either naturally or artificially formed into ports, and then again to distribute to every part of the country the goods brought in exchange from foreign lands, comprising frequently the necessaries as well as the luxuries of human life.

And further, good means of internal communication are essential for the proper defence of a country (whether island or continental) against either the attacks of foreign aggressors or civil tumults, rendering a much smaller standing army necessary for this purpose than would otherwise be required.

Such being the case, it will not be a matter of surprise that, from the earliest periods, and in all nations having any pretensions to civilization, the establishment and improvement of the means of internal communication has always been regarded as a consideration of primary importance; and one which has engaged the highest talents of the Military or Civil Engineer, the result of whose exertions, devoted to the accomplishment of this object, has been the perfection of common roads, railways, and canals.

It is not necessary to enter into the comparative merits or advantages of these several means of communication, in order to establish the importance and necessity of common roads. For although, under certain circumstances, it might be questionable which of the three would be the best adapted for serving the tract of country through which it was to pass, there are an innumerable number of cases in which only the common road could be advantageously employed. Railways and navigable rivers or canals may be regarded as the arteries of traffic; while common roads are simply the veins or smaller ramifications through which the means of conveyance are carried into every nook and corner of the land. It would be quite impracticable so to intersect any country with canals or railways as to obviate the necessity of common roads, or to make the former universally supersede the latter.

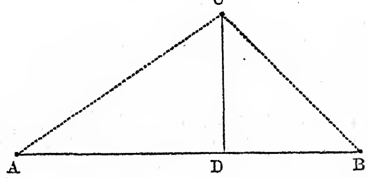
The formation of a perfect general system of railway communication necessitates the construction of several new common roads, in order that towns situated at some distance from the nearest line of railway may fully participate in the benefits to be derived from it.

Before entering into practical details on the construction of such roads, it will be desirable to explain the manner in which a person should proceed in exploring a tract of country for the purpose of determining the best course for a road, and the principles which should guide him in his final selection of the same.

Let us suppose that it is desired to form a road between two distant towns, A and B,

fig. 1, and let us, for the present, neglect altogether the consideration of the physical features of the intervening country; assuming that it is equally favourable, whatever

Fig. 1.



line we select. At first sight it would appear that, under such circumstances, a perfectly straight line drawn from one town to the other would be the best that could be chosen. On a more careful examination, however, of the locality, we may find that there is a third town, C, situated somewhat on one side of the straight line which we have drawn from A to B; and although our primary object is to connect only the two latter, that it would, nevertheless, be of considerable service if the whole of the three towns were put into mutual connection with each other. Now this may be effected in three different ways; any one of which might, under certain circumstances, be the best. In the first place we might, as originally suggested, form a straight road from A to B, and in a similar manner, two other straight roads from A to C, and from B to C, and this would be the most perfect way of effecting the object in view; the distance between any two of the towns being reduced to the least possible. It would, however, be attended with considerable expense, and it would be requisite to construct a much greater length of road than according to the second plan, which would be to form, as before, a straight road from A to B, and from C to construct a road which should join the former at a point D, so as to be perpendicular to it; the traffic between A or B and C would proceed to the point D, and then turn off to C; with this arrangement while the length of the roads would be very materially decreased, only a slight increase would be occasioned in the distance between C and the other two towns. The third method would be to form only the two roads A C and C B, in which case the distance between A and B would be somewhat increased, while that between A and C, or B and C, would be diminished; the total length of road to be constructed would also be lessened.

As a general rule, it may be taken, that the last of these methods is the best, and most convenient for the public; that is to say, that if the physical character of the country does not determine the course of the road, it will generally be found best not to adopt a perfectly straight line, but to vary the line so as to pass through all the principal towns near its general course; for the reason that the public may be conveyed from town to town with greater facility and less expense than if the straight line were adopted, and the towns were merely made to communicate with it by means of branch roads; since, with the first arrangement, any vehicles established to convey passengers or goods between the two terminal towns would pass through all those which were intermediate; while, if the straight line and branch road system were adopted, it would be requisite also to have a system of branch coaches to meet the coaches on the main line.

In laying out a road in an old country which has been long inhabited, and in which the position of the various towns, &c., requiring road accommodation is therefore already determined, we are left less at liberty in the choice and selection of the line of road, and must be guided in that choice by different considerations to those which would determine the line of a road made through a new country, where our only object was to establish the easiest and best road between two distant

stations. In the first case we should take into consideration the position of the various towns and other inhabited districts situated near the intended road, and its course would be, to a certain extent, controlled thereby; while, in the second case, we should simply examine the physical character of the country, and base all our proceedings on the result.

Whichever of these two cases, however, may have to be dealt with, in the ultimate selection and adoption of the line of road between these points which are fixed by other circumstances, the same careful examination of the physical character of the country should be made, and the same principles should control the choice.

In examining almost any tract of country, one of the first points which must attract our notice is the unevenness or undulation of its surface; but if we extend our observation a little further, we shall perceive, even in the most apparently irregular countries, the same general principle of conformation. We shall find the country intersected in various directions by rivers decreasing in size as they leave their point of discharge; from these main rivers we shall find lesser ones branching off on both sides, and running right and left through the country, and from these again still smaller streams and brooks; furthermore we shall find the ground falling in every direction towards these natural watercourses, forming a ridge, more or less elevated, running between them, and separating from each other the districts drained by each separate stream.

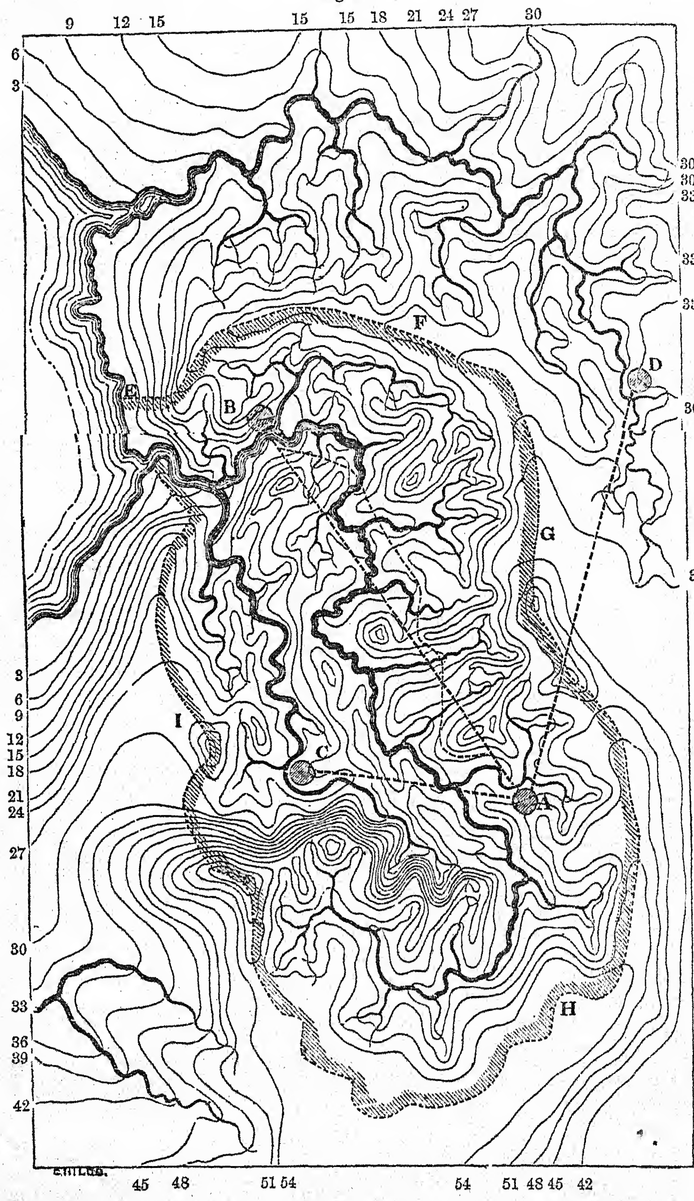
In all cases it should be the first business of a person, engaged in laying down a line of road, to make himself thoroughly acquainted with all these features of the country: he should possess himself of a plan or map, shewing accurately the course of all the rivers and principal watercourses, and upon this he should further mark the lines of greatest elevation, or the ridges separating the several valleys through which they flow; it would also be of peculiar service if the plan contained contour lines shewing the comparative levels of any two points, and the rates of declivity of every portion of the country's surface. The system of shewing upon plans the levels of the ground by means of *contour lines* is one of much utility, not only in the selection of roads and all other lines of communication, but in the drainage of towns as well as their supply with water, in the drainage and irrigation of lands, and for almost all purposes.*

The annexed plan (fig. 2) shews an imaginary tract of country, to illustrate more clearly the mode of shewing by means of contour lines the physical features which may belong to it. The hatched line, E F G H I, is supposed to be the elevated ridge, encircling the valley shewn in the plan; the fine black lines are contour lines, indicating that the ground over which they pass is at the altitude above some known mark expressed by the figures placed against them in the margin; and it will be observed that these lines, by their greater or less distance, produce the effect of shading, and make apparent to the eye, at one view, the undulations and irregularities in the surface of the country.

In laying out a line of road there are three cases which may occur, and each of these is exemplified in the plan (fig. 2); first, the two places to be connected may be both situated in the same valley, and upon the same side of it, that is, not separated from each other by the main stream which drains the valley, as the towns A and B on the plan, and this is the simplest case which can occur; secondly, although both in the same valley, they may be on opposite sides of the valley, as A and C, being separated by the main river; thirdly, they may be situated in different valleys, so as to be separated by an intervening ridge of ground more or less elevated, as A and D.

* See article 'Contouring,' vol. i.

Fig. 2.



In laying out an extensive line of road, it frequently happens that each of these c occurs, and that, perhaps, frequently, during its course; we shall, therefore, proceed to point out the various methods which might in each case be pursued,

afterwards to lay down the general principles which should determine our choice of them.

Before doing so, however, we should perhaps observe, although it must be almost obvious to all, that the most perfect condition of a road is that in which its course is perfectly straight and its surface perfectly level; and that, all other things being the same, that is the best road which approaches nearest to this state.

Now, in the first case supposed (that of two towns situated on the same side of the main valley), there are two methods which might be pursued in forming a communication between them: we might either make a road following the direct line between them, shewn by the thick dotted line A B, or we might adopt a line which should gradually and equally incline from one town to the other, supposing them to be at a different level, or if at the same, keeping at that level throughout its entire course, and following all the sinuosities and curves which the irregular formation of the country might render necessary for the fulfilment of these conditions. And in the first method (that of a direct line between the two places), we might either form a level or equally-inclined road from one to the other, forming embankments and cuttings where necessary to attain these objects, or we might avoid these expensive works and make the surface of the road conform to that of the country. Now, of all these the best is the straight and equally-inclined (or level, as the case may be) road, although at the same time it is the most expensive; and if the importance of the traffic passing between the places is not sufficient to warrant so great an outlay, it will then become a matter of consideration whether the course of the road should be kept straight, its surface being made to undulate with the natural face of the country, or whether, a level or equally-inclined line being taken for its surface, the course of the road should be made to deviate from the direct line, and follow the winding course which such a condition is supposed to necessitate.

In the second case, that of two places situated on opposite sides of the same valley, we have in like manner the choice of a perfectly straight line to connect them, which would probably require a heavy embankment if the road were kept level, or steep inclines if it followed the surface of the country; or we may, by winding the road, carry it across the valley at a higher point, where, if the level road were taken, the embankment would not be so high, or, if kept on the surface, the inclination would be reduced.

In the third case, we have in like manner the alternative of carrying the road across the intervening ridge in a perfectly straight line, or of deviating to the right or left and crossing at a point where the ridge is less elevated.

In all these cases, the proper determination of the question which of these courses is the best under certain circumstances, involves one of the most difficult points to solve, which is, the comparative advantages and disadvantages of inclines and curves; that is, what additional increase in the length of a road would be equivalent to a given inclined plane upon it, or conversely, what inclination might be given to a road as an equivalent to a given decrease in its length. In order to a correct solution of these questions, it is requisite that we should know the comparative force required to draw different vehicles with given loads upon level and variously inclined roads. We shall, therefore, before proceeding further, investigate this subject, and shew the manner in which we may determine the tractive force required upon roads of any given inclination.

It has been attempted to investigate mathematically the resistances which oppose themselves to the motion of various descriptions of vehicles drawn along horizontal roads, whose surfaces were formed of different materials and in different states of smoothness. No satisfactory result, however, has been obtained, because we are

ignorant of the data which are essentially requisite to enable us to arrive at a correct conclusion. We should, for instance, know the relative amounts of resistance occasioned by a wheel drawn along a hard smooth road, such as a good macadamized road so hard that the wheel can make no appreciable impression upon it; upon the same road when newly covered with stones, and when the passing of the wheel over them crushes these stones, in a greater or less degree; upon a gravel road the surface of which is soft, so that the wheel in its passage sinks into the road and forms a rut; upon a similar road covered with stones which are partially crushed and partially forced down into the soft road by the wheel passing over them; or upon a stone pavement, such as is common in the streets of towns, laid with more or less regularity, and in passing over which the resistance is felt in jerks, as the wheels bound from stone to stone. Many other cases might be mentioned, in which we should be equally at a loss to assign a correct value to the resistance which would be experienced by a carriage drawn along the particular description of road supposed. Although, therefore, some of the attempts which have thus been made have been very ingenious, and have shewn the mathematical skill of the investigator, they have done little besides, and would be out of place in the present article. In cases of this description, the best practical method of proceeding is by experiments sufficiently careful and extensive to determine the amount of resistance, in each particular case, from which we may then determine an empirical formula or rule, which will enable us to generalize the results of our experiments, and apply them with sufficient accuracy for practical purposes to any particular case.

The following are the general results of the experiments made by M. Morin upon this subject, at the expense of the French Government:—

1st. The traction is directly proportional to the load, and inversely proportional to the diameter of the wheel.

2nd. Upon a paved or hard macadamized road the resistance is independent of the width of the tire, when it exceeds from three to four inches.

3rd. At a walking pace the traction is the same, under the same circumstances, for carriages with springs and without them.

4th. Upon hard macadamized and upon paved roads the traction increases with the velocity; the increments of traction being directly proportional to the increments of velocity above the velocity 3·28 feet per second, or about $2\frac{1}{4}$ miles per hour. The equal increment of traction thus due to each equal increment of velocity is less as the road is more smooth, and the carriage less rigid or better hung.

5th. Upon soft roads of earth, or sand or turf, or roads fresh and thickly gravelled, the traction is independent of the velocity.

6th. Upon a well-made and compact pavement of hewn stones, the traction at a walking pace is not more than three-fourths of that upon the best macadamized roads under similar circumstances: at a trotting pace it is equal to it.

7th. The destruction of the road is in all cases greater as the diameters of the wheels are less, and it is greater in carriages without than with springs.

The next experiments which we shall quote are those of Sir John Macneill,* made with an instrument invented by him for the purpose of measuring the tractive force required on different descriptions of road, under various circumstances. The general results which he obtained are given in the following Table, the numbers in which exhibit the tractive force requisite to move a weight of a ton, under ordinary circumstances, at a very low velocity upon the several kinds of road mentioned.

* Sir H. Parnell on Roads, p. 73.

Description of Road.	Force, in lbs., required to move a ton.
On a well-made pavement	33
On a road made with 6 inches of broken stone of great hardness, laid either on a foundation of large stones, set in the form of a pavement, or upon a bottoming of concrete	46
On an old flint road, or a road made with a thick coating of broken stone, laid on earth	65
On a road made with a thick coating of gravel, laid on earth	147

Sir John Macneill has also given the following arbitrary formulæ for calculating the resistance to traction on various kinds of roads: they have been deduced from a considerable number of experiments made on the different kinds of road specified below, with carriages moving at various velocities. Putting R for the force required to move the carriage, W the weight of the carriage, w that of the load, all expressed in lbs., v the velocity in feet per second, and c a constant number, which depends upon the surface over which the carriage is drawn, and the value of which for several different kinds of road is as follows—

On a timber surface	$c = 2$
On a paved road	,, 2
On a well-made broken stone road, in a dry clean state	,, 5
On a well-made broken stone road, covered with dust	,, 8
On a well-made broken stone road, wet and muddy	,, 10
On a gravel or flint road, in a dry clean state	,, 13
On a gravel or flint road, in a wet muddy state	,, 32

we have, in the case of a common stage waggon,

$$R = \frac{W + w}{93} + \frac{w}{40} + c\,v\,; \qquad (1.)$$

and in the case of a stage coach,

$$R = \frac{W + w}{100} + \frac{w}{40} + c\,v\,; \qquad (2.)$$

These formulæ, being reduced to verbal rules for the convenience of those not conversant with algebraical expressions, are as follows:

Rule.—Divide the weight of the carriage when loaded, in lbs., by 93 if a waggon, or 100 if a coach, and to the quotient add $\frac{1}{40}$th of the weight of the load only; the sum, added to the velocity in feet per second, multiplied by the proper number taken from the above Table for the particular kind of road, will give the force in lbs. required to draw the carriage at the given velocity upon that description of road.

For example: what force would be requisite to move a stage coach weighing 2060 lbs., and having a load of 1100 lbs., at a velocity of 9 feet per second, along a broken stone road covered with dust?

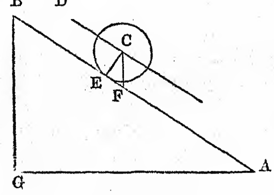
Here we have

$$\frac{2060 + 1100}{100} + \frac{1100}{40} + 8 \times 9 = 131{\cdot}1 \text{ lbs. for the force required.}$$

We next pass on to consider the additional resistance which is occasioned when the road, instead of being level, is inclined in a greater or less degree. In order to

simplify the question, let us suppose the whole weight to be supported on one pair of wheels, and that the tractive force is applied in a direction parallel to the surface of the road. On this supposition let A B (fig. 3) represent a portion of an inclined road, C being a carriage just sustained in its position by a force acting in the direction C D : now it is evident that the carriage is kept in its position by three forces; namely, by its own weight (equal W) acting in the vertical direction C F, by the force (equal F) applied in the direction C D parallel to the surface of the road, and by the pressure (equal P) which the carriage exerts against the surface of the road acting in the direction C E, perpendicular to the same. To determine the relative magnitude of these three forces, draw the horizontal line A G, and the vertical one B G; then, since the two lines C F and B G are parallel, and are both cut by the line A B, they must make the two angles C F B and A B G equal; also the two angles C E F and A G B are equal, being both right angles; therefore the remaining angles F C E and B A G are equal, and the two triangles C F E and A B G are similar. And as the three sides of the former are proportional to the three forces by which the carriage is sustained, so also are the three sides of the latter, namely, A B, or the length of the road is proportional to W, or the weight of the carriage, B G, or the vertical rise in the same to F, or the force required to sustain the carriage on the incline, and A G or the horizontal distance in which this rise occurs to P, or the force with which the carriage presses upon the surface of the road.

Fig. 3.



We have, therefore,

$$W : AB :: F : GB,$$

$$\text{and } W : AB :: P : AG.$$

And if we make A G such a length that the vertical rise of the road is exactly 1 foot, we shall have

$$F = \frac{W}{AB} = \frac{W}{\sqrt{AG^2 + 1}} = W \cdot \sin \beta \quad . \quad . \quad . \quad . \quad . \quad . \quad (3.)$$

$$\text{and } P = \frac{W.\ AG}{AB} = \frac{W\ .\ AG}{\sqrt{AG^2+1}} = W.\ \cos \beta \quad . \quad . \quad . \quad . \quad (4.)$$

in which β is the angle B A G.

These formulæ reduced to verbal rules are as follows:

To find the force requisite to sustain a carriage upon an inclined road (the effects of friction being neglected), divide the weight of the carriage, including its load, by the *inclined* length of the road, the vertical rise of which is 1 foot, and the quotient is the force required.

To find the pressure of a carriage against the surface of an inclined road, multiply the weight of the loaded carriage by the *horizontal* length of the road, and divide the product by the *inclined* length of the same; the quotient is the pressure required

Example.—What is the force required to sustain a carriage weighing 3270 lbs. upon a road the inclination of which is 1 in 30, and what is the pressure of the same upon the surface of the road?

Here the horizontal length of the road (A G) being 30, the inclined length ($AB = \sqrt{AG^2 + 1}$) is 30·017, and we have, by the first rule, 3270÷30·017=

108·93 lbs. for the force required to sustain the carriage on the road; and, by the second rule, (3270 × 30) ÷ 30·017 = 3269·9 lbs. for the pressure of the carriage upon the surface of the road.

Since the pressure of a carriage on a sloping road is found by multiplying its weight by the horizontal length of the road and dividing by the inclined length, and as the former is always less than the latter, it follows that the force with which a carriage bears upon an inclined road is less than its actual weight, as will be seen in the foregoing example, in which it is about 2 lbs. less: unless, however, the inclination is very steep, it is not necessary to calculate the pressure, which may be assumed to be equal to the weight of the carriage.

If R expresses the resistance which has to be overcome in moving any particular carriage at a given rate upon a horizontal road, then R + F will be the resistance upon ascending a hill, and R − F upon descending a hill, with the same velocity, in both cases neglecting the decrease in the weight of the carriage produced by the inclination of the road. Taking, however, this decrease into consideration, the following modification in the formulæ (1) and (2) will be requisite to adapt them to an inclined road—

$$R = \left(\frac{W +}{93} + \frac{w}{40}\right) . \cos\beta \mp (W + w) . \sin\beta + c\,v \quad . \quad . \quad (5)$$

in the case of a common stage waggon, and in that of a stage coach,

$$R = \left(\frac{W + w}{100} + \frac{w}{40}\right) . \cos\beta \mp (W + w) . \sin\beta + c\,v \quad . \quad . \quad (6)$$

the upper sign being taken when the vehicle is drawn down the incline, and the lower when it is drawn up the same.

Neglecting the decrease in the weight of the carriage, in order to ascertain the resistance in passing up or down a hill, we have only to calculate by the rule already given at page 305, the resistance on a level road, to which, if the carriage ascends the hill, we must add, or if it descends, subtract, the force requisite to sustain the carriage on the inclined road, calculated by the rule already given: the sum or difference, as the case may be, will express the resistance required.

As an example, let us take, as before, the case of a stage coach weighing 2060 lbs., besides a load of 1100 lbs., and having to be moved at a velocity of 9 feet per second, along a broken stone road whose surface is covered with dust, and inclined at the rate of 1 in 30.

Then the force to sustain the coach on this slope will be

$$\frac{3160}{30} = 105{\cdot}3 \text{ lbs.};$$

which, added to the force already found at page 305 as being requisite to move the same coach on a level road, will be (105·3 + 131·1 =) 236·4 lbs. for the force required to move the coach with a velocity of 9 feet per second *up* an inclination of 1 in 30; and subtracted from the same, will be (131·1—105·3 =) 25·8 lbs., the force required to move the coach with the same velocity *down* the same inclination.

The same example worked by formula (6) will give

$$\left(\frac{2060 + 1100}{100}\right) \cdot 9995 + (2060 + 1100) \cdot 0333 + 8 \times 9 = 236{\cdot}3 \text{ lbs.}$$

when the carriage is drawn up the incline, and

$$\left(\frac{2060 + 1100}{100}\right) \cdot 9995 - (2060 + 1100) \cdot 0333 + 8 \times 9 = 25{\cdot}84 \text{ lbs.}$$

when the carriage is drawn down the incline, the result being the same as that given by the rule.

The following Table has been calculated in order to shew with sufficient exactness for most practical purposes the force required to draw carriages over inclined roads, and the comparative advantage of such roads and those which are perfectly level. The first column expresses the rate of inclination, and the second the equivalent angle; the two next columns contain the force requisite to draw a common stage waggon weighing with its load 6 tons, at a velocity of 4·4 feet per second (or 3 miles per hour) along a macadamized road in its usual state, both when the hill ascends and when it descends; the fifth and sixth columns contain the length of level road which would be equivalent to a mile in length of the inclined road, that is, the length which would require the same mechanical force to be expended in drawing the waggon over it as would be necessary to draw it over a mile of the inclined road. The four next columns contain the same information as the four last described, only with reference to a stage coach supposed to weigh with its load 3 tons, and to travel at the rate of 8·8 feet per second, or 6 miles per hour.

The Table may be also considered as affording a view of the comparative disadvantage of hilly roads with light and heavy traffic; the stage waggon, weighing 6 tons and travelling at the speed of 3 miles per hour, may be taken as a fair average for goods traffic, and the stage coach, weighing 3 tons and running 6 miles an hour, for passenger traffic. From the Table we perceive that hills act much more unfavourably on the former than on the latter. The force which would be requisite to move the waggon on a level road would be 264 lbs., and that to move the coach 362 lbs., being an excess of 98 lbs. or the traction of the coach; but with a road inclined at the rate of 1 in 600, this excess is only (373 − 286 =) 87 lbs., and when the inclination of the road amounts to about 1 in 70 the forces required to draw them become equal: as the inclination of the road increases beyond this, the excess of the force requisite to draw the waggon over that necessary to move the coach increases rapidly (as will be seen in the Table), until, at an inclination of 1 in 7, it amounts to (2162 − 1308 =) 854 lbs.

If we compare the forces required to draw either the waggon or coach up and down any given incline, we shall find that the former is as much greater than the force required on a level road as the latter is less than the same: it might thence be concluded that in the case of a vehicle passing alternately along the road, no real loss would be occasioned by the inclination of the road, since as much power would be gained in the descent of the hill as was lost in its ascent. Such is not, however, practically the fact, for while the inclinations of the road render it necessary in the ascending journey to have either a greater number or more powerful horses than would be requisite if the road were entirely level, no corresponding reduction can be made in the descending journey; we must still have horses sufficient to draw the vehicle along the level portions of the road; nor will (generally speaking) the horses have less to do in descending the hill, since they have frequently to push back, to prevent the speed of the coach becoming accelerated beyond the bounds of safety.

In a practical point of view, therefore, we may consider that the fifth and ninth columns in the following Table express the length of level road which would be equivalent to a mile of road with the stated inclination, the former giving the result for heavy traffic, and the latter for passenger traffic. Opposite 1 in 75, we find in the ninth column 1·247 mile, or nearly a mile and a quarter, stated as the length of a road having that inclination which would be equivalent to one mile of a similar road perfectly level, because the same force would be requisite to move a coach and load of 3 tons at a velocity of 6 miles per hour along one as along the other.

Rate of Inclination.	Angle with the horizon.	For a Stage Waggon. Force required to draw the waggon *up* the incline.	Force required to draw the waggon *down* the incline.	Equivalent length of level road for an *ascending* waggon.	Equivalent length of level road for a *descending* waggon.	For a Stage Coach. Force required to draw the coach *up* the incline.	Force required to draw the coach *down* the incline.	Equivalent length of level road for an *ascending* coach.	Equivalent length of level road for a *descending* coach.
		lbs.	lbs.	miles.	miles.	lbs.	lbs.	miles.	miles.
1 in 600	0° 5′ 44″	286	241	1·085	·9150	373	350	1·030	·9690
,, 575	0 5 59	287	240	1·088	·9116	373	350	1·032	·9676
,, 550	0 6 15	288	239	1·093	·9074	374	349	1·033	·9662
,, 525	0 6 33	289	238	1·097	·9029	374	349	1·035	·9646
,, 500	0 6 53	291	237	1·102	·8979	375	348	1·037	·9629
,, 475	0 7 14	292	235	1·107	·8926	376	347	1·039	·9605
,, 450	0 7 38	294	234	1·113	·8869	377	347	1·041	·9588
,, 425	0 8 5	295	232	1·120	·8801	377	346	1·043	·9563
,, 400	0 8 36	297	230	1·128	·8725	378	345	1·046	·9535
,, 375	0 9 10	300	228	1·136	·8642	380	344	1·049	·9505
,, 350	0 9 49	302	225	1·146	·8543	381	342	1·053	·9469
,, 325	0 10 35	305	222	1·157	·8433	382	341	1·056	·9430
,, 300	0 11 28	309	219	1·170	·8301	384	339	1·061	·9381
,, 290	0 11 51	310	217	1·176	·8245	385	338	1·064	·9358
,, 280	0 12 17	312	216	1·182	·8179	386	338	1·066	·9336
,, 270	0 12 44	314	214	1·189	·8111	386	337	1·068	·9314
,, 260	0 13 13	315	212	1·196	·8039	387	336	1·071	·9286
,, 250	0 13 45	317	210	1·204	·7963	388	335	1·074	·9259
,, 240	0 14 19	320	208	1·212	·7876	390	334	1·077	·9226
,, 230	0 14 57	322	205	1·222	·7785	391	332	1·080	·9192
,, 220	0 15 37	325	203	1·232	·7683	392	331	1·084	·9156
,, 210	0 16 22	328	200	1·243	·7573	394	330	1·088	·9115
,, 200	0 17 11	331	197	1·255	·7451	395	328	1·092	·9071
,, 190	0 18 6	334	193	1·268	·7319	397	326	1·097	·9024
,, 180	0 19 6	338	189	1·283	·7171	399	324	1·103	·8968
,, 170	0 20 13	343	185	1·300	·7004	401	322	1·109	·8908
,, 160	0 21 29	348	180	1·319	·6814	404	320	1·116	·8839
,, 150	0 22 55	353	174	1·341	·6587	406	317	1·123	·8761
,, 140	0 24 33	360	168	1·364	·6359	410	314	1·132	·8673
,, 130	0 26 27	367	160	1·392	·6079	413	310	1·142	·8573
,, 120	0 28 39	376	152	1·425	·5752	418	306	1·154	·8451
,, 110	0 31 15	386	142	1·451	·5491	423	300	1·169	·8308
,, 100	0 34 23	398	129	1·510	·4903	429	294	1·185	·8142
,, 95	0 36 11	405	122	1·537	·4634	432	291	1·195	·8045
,, 90	0 38 12	413	114	1·566	·4338	436	287	1·206	·7937
,, 85	0 40 27	422	106	1·600	·4004	441	282	1·219	·7801
,, 80	0 42 58	432	96	1·637	·3629	446	278	1·232	·7677

Rate of Inclination.	Angle with the horizon.	For a Stage Waggon. Force required to draw the waggon *up* the incline	Force required to draw the waggon *down* the incline.	Equivalent length of level road for an *ascending* waggon.	Equivalent length of level road for a *descending* waggon.	For a Stage Coach. Force required to draw the coach *up* the incline.	Force required to draw the coach *down* the incline.	Equivalent length of level road for an *ascending* coach.	Equivalent length of level road for a *descending* coach.
		lbs.	lbs.	miles.	miles.	lbs.	lbs.	miles.	miles.
1 in 75	0° 45′ 51″	443	85	1·680	·3204	451	272	1·247	·7522
,, 70	0 49 7	456	72	1·728	·2719	457	266	1·265	·7345
,, 65	0 52 54	470	57	1·784	·2161	465	258	1·285	·7143
,, 60	0 57 18	488	40	1·850	·1505	474	250	1·309	·6903
,, 55	1 2 30	508	19	1·926	·0736	484	239	1·337	·6620
,, 50	1 8 6	533	—	2·019	—	496	227	1·371	·6283
,, 45	1 16 24	562	—	2·133	—	511	212	1·412	·5871
,, 40	1 25 57	600	—	2·274	—	530	194	1·464	·5354
,, 35	1 38 14	648	—	2·456	—	554	170	1·530	·4690
,, 34	1 41 8	659	—	2·499	—	559	164	1·546	·4535
,, 33	1 44 12	671	—	2·544	—	565	158	1·562	·4370
,, 32	1 47 27	684	—	2·593	—	572	152	1·580	·4193
,, 31	1 50 55	697	—	2·644	—	578	145	1·599	·4007
,, 30	1 54 37	712	—	2·699	—	586	138	1·619	·3805
,, 29	1 58 34	727	—	2·758	—	593	130	1·640	·3592
,, 28	2 2 5	744	—	2·820	—	602	122	1·663	·3363
,, 27	2 7 2	762	—	2·888	—	610	113	1·688	·3119
,, 26	2 12 2	781	—	2·960	—	620	103	1·714	·2854
,, 25	2 17 26	801	—	3·038	—	630	93	1·743	·2566
,, 24	2 23 10	823	—	3·120	—	641	82	1·774	·2257
,, 23	2 29 22	847	—	3·213	—	653	69	1·808	·1919
,, 22	2 36 10	874	—	3·313	—	666	56	1·844	·1554
,, 21	2 43 35	903	—	3·423	—	681	42	1·884	·1150
,, 20	2 51 21	933	—	3·538	—	696	26	1·926	·0730
,, 19	3 0 46	970	—	3·677	—	714	8	1·977	·0221
,, 18	3 10 47	1009	—	3·826	—	734	—	2·032	—
,, 17	3 21 59	1053	—	3·991	—	756	—	2·092	—
,, 16	3 34 35	1102	—	4·178	—	780	—	2·160	—
,, 15	3 48 51	1157	—	4.388	—	807	—	2·234	—
,, 14	4 5 14	1221	—	4·629	—	839	—	2·322	—
,, 13	4 23 56	1294	—	4·906	—	875	—	2·423	—
,, 12	4 45 49	1379	—	5·229	—	918	—	2·540	—
,, 11	5 11 40	1480	—	5·611	—	968	—	2·679	—
,, 10	5 42 58	1600	—	6·067	—	1028	—	2·846	—
,, 9	6 20 25	1747	—	6·623	—	1101	—	3·048	—
,, 8	7 7 30	1929	—	7·315	—	1192	—	3·300	—
,, 7	8 7 48	2162	—	8·199	—	1308	—	3·621	—

Although, however, they might be considered equal as far as the power requisite for traction was concerned, in other respects one might be more advantageous than the other; as, for instance, the shorter road would cost least for repairing, and would occupy least time in being passed over. The Table, therefore, merely expresses the equivalent length as far as the mechanical power required for the traction is concerned; the relative merits in other respects depending generally upon so many various circumstances as to render it quite impossible to lay down any specific rules for their determination.

We shall now return to the subject of the selection of route, and proceed to explain the course which should be pursued to obtain the requisite data, to enable a correct determination to be arrived at.

In laying out a new line of road, the first proceeding is usually, after a general examination of the country, to lay down upon the best map which can be procured one or more lines, for the purpose of being more carefully examined. If possessed of a contour map of the district, such as we have described, this proceeding will be greatly facilitated; we shall, however, suppose that such is not the case, since there are very few instances in which a road-maker would be likely to find such a plan for his use. His next proceeding should be, to make an accurate survey of the lands through which the several lines that he has sketched out pass, which should be afterwards plotted, or laid down to such a scale as will allow the smallest features to be shewn with sufficient accuracy and distinctness: a scale of 10 chains to the inch for the open country, with enlarged plans of towns and villages upon a scale of 3 chains to the inch, will generally be found sufficient. Careful levels should also be taken along the course of each line, and at certain distances (depending upon the nature of the country) lines of levels should be taken at right angles with the original line. In taking these levels the heights of all existing roads, rivers, streams, or canals, should be noted, and *bench marks* should be left at least every half mile, that is, marks made on any fixed object, such as a gate-post, or the side of a house or barn, &c., the exact height of which is ascertained, and registered in the level-book, so that, in case of a deviation being made in any portion of the line, the levels of that part may be taken without the necessity of again going over the other parts of the line. A section should be formed from these levels, having the same horizontal scale as the general plan, and such a vertical scale as will shew with distinctness the inequalities of the ground: if the horizontal scale is 10 chains to the inch, the vertical scale may be 20 feet to the inch.

Fig. 4 (p. 312) is supposed to be such a plan as we have described, plotted on a scale of 10 chains to the inch, and shewing a district through which it is wished to form a road: we have shewn one line running nearly straight across the plan, and a deviation therefrom, which, although longer, would run on more favourable ground. Figs. 5 and 6 (pp. 313, 314) are sections shewing the levels of the surface, the former on the straight line, and the latter on the deviation from it. We have shewn in these sections and on the plan the information which will be requisite in enabling the Engineer to lay down the course of the road, and to arrange the position and dimensions of the various culverts, bridges, and other works belonging to the same.

By reference to these drawings, it will be seen (fig. 4) that the straight line has to cross a stream at B, and the river twice at C and D; and also that it must pass from B to E, over a swamp or morass of such a nature that, if a solid embankment is formed, it is probable that a very large quantity of ground will be absorbed beyond what the section would indicate; added to which, from the river being liable to be flooded, it will be necessary to form bridges with several capacious openings at those points where the intended road crosses the river. These disadvantages attending the

more obvious route would induce the Engineer to sketch out some other line, by which they would be avoided. And he would then have the levels taken, and the requisite information, to enable him to choose between the two.

The manner in which the sections should be drawn, and the information to be given upon them, are shewn in figs. 5 and 6. In addition to which the following data should be obtained, and entered either in the survey field-book or in the level-book.

At the point B (fig. 4) the line crosses a stream 8 feet in width and 1 foot deep; in flood this stream brings down a considerable quantity of water.

At the point C on the section the river is much narrower and not so deep as at other places, in consequence of a great portion of its waters finding a passage through the marshy ground on either side. Its width is 16 feet; and its depth 2 feet; the velocity of its current is 95 feet per minute; the height of its surface at the present time is 30·10 feet above the datum; and the angle of skew which the course of the stream makes with the line of the road is 62 degrees.

At the point D the river is 27 feet wide, and $2\frac{1}{2}$ feet in depth; its velocity 87 feet per minute; the height of its surface above the datum 29·96 feet; and the angle of skew 49 degrees.

The ground from B to E is of a very soft boggy nature and full of water.

The height to which the river has risen during the highest flood known, at the bridge at F on the plan, is 35 feet above the datum; the waterway at that time was 90 feet, and the sectional area of the openings through which the water then flowed was 550 square feet. The same flood at the lower bridge, at G on the plan, was 35·3 feet above the datum; the waterway was 102 feet, and the sectional area nearly 600 square feet.

The deviation line only crosses one stream at M on the plan and section. The present width of this stream is 15 feet, and its depth 18 inches; but in times of flood it rises to the same height as the river, and brings down a large body of water. The present height of its surface above the datum is 31·25 feet, and the angle which its course makes with the line of road 85 degrees.

We have introduced the foregoing in order to shew the kind of data which should be obtained by those engaged in taking the levels and survey for road-making.*

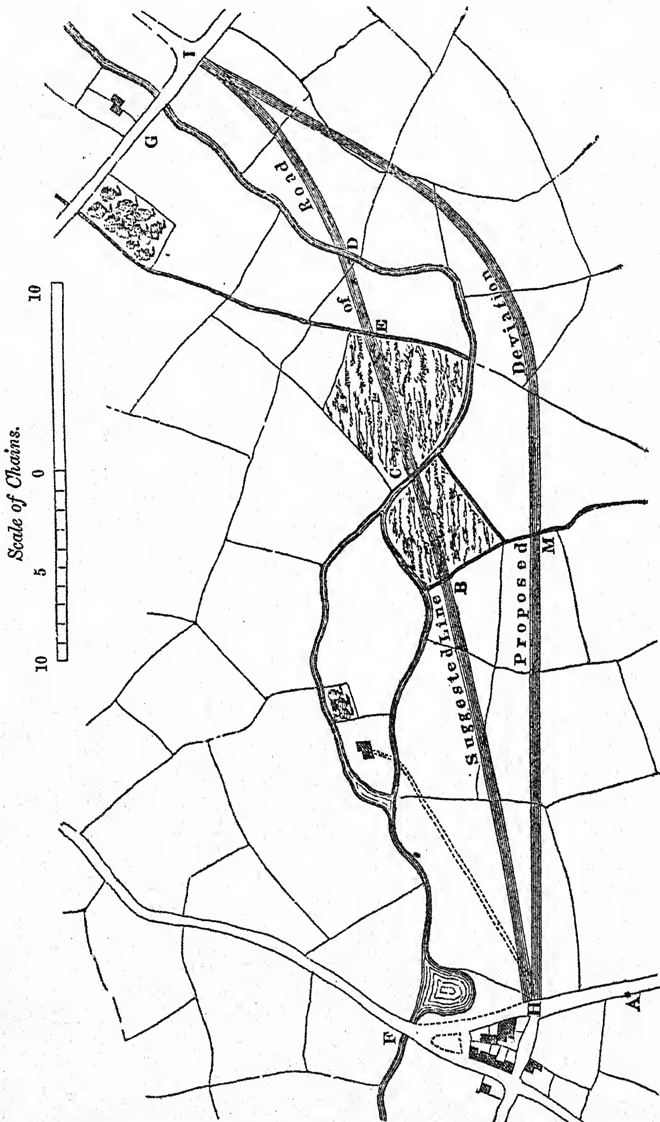
A cross section should also be taken of each of the existing roads near their junction with the intended road; the use of which is to shew to what extent, if any, the levels of the existing roads might be altered, the better to suit that of the new road.

Possessed of the sections, figs. 5 and 6, we next proceed to lay down the line of the road, or, in other words, to determine the levels at which it shall be formed. As it is desirable that the road should always be dry, it should be at least a foot above the level of the flood; and if kept at 37·25 feet above the datum, which is the height of the existing road at I, we shall effect this object. Upon drawing a line at this level upon the section, we perceive that an embankment will have to be formed from the road at I, across the valley to the point where this line meets the ground at K, and that the remainder of the road from K to H will be in a cutting. Now the obvious principle, in arranging the levels of a road, would be so to adjust the cuttings and embankments that the ground taken from one should form the other. In the present instance, however, this is impossible, because the level of the road is determined by other circumstances, and necessitates the formation of a very long embankment with

* The information relative to the rivers crossed, such as is given above, should always be obtained, in order that the bridges constructed over them may be adequate for the passage of the water brought down in time of floods.

but very little cutting, therefore rendering it necessary for ground to be obtained from some other source, with which to form the embankment. In order to produce as much cutting as possible, the line should be kept at the same level as before until

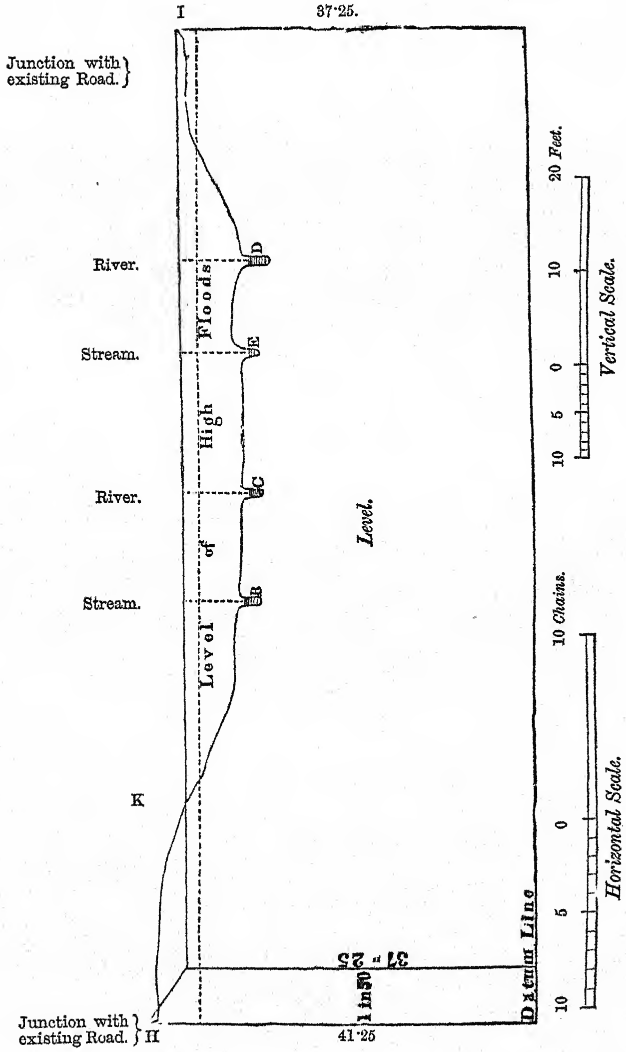
Fig. 4.



it becomes necessary to rise to attain the level of the existing road at H : if an inclination of 1 in 50 be given to this last part of the road, the distance at which the rise

will commence will be 200 feet from H, the difference of level being 4 feet. We have therefore to add to the other disadvantages already mentioned, as belonging to the straight line of road, that of requiring the formation of a large embankment, and the

Fig. 5.

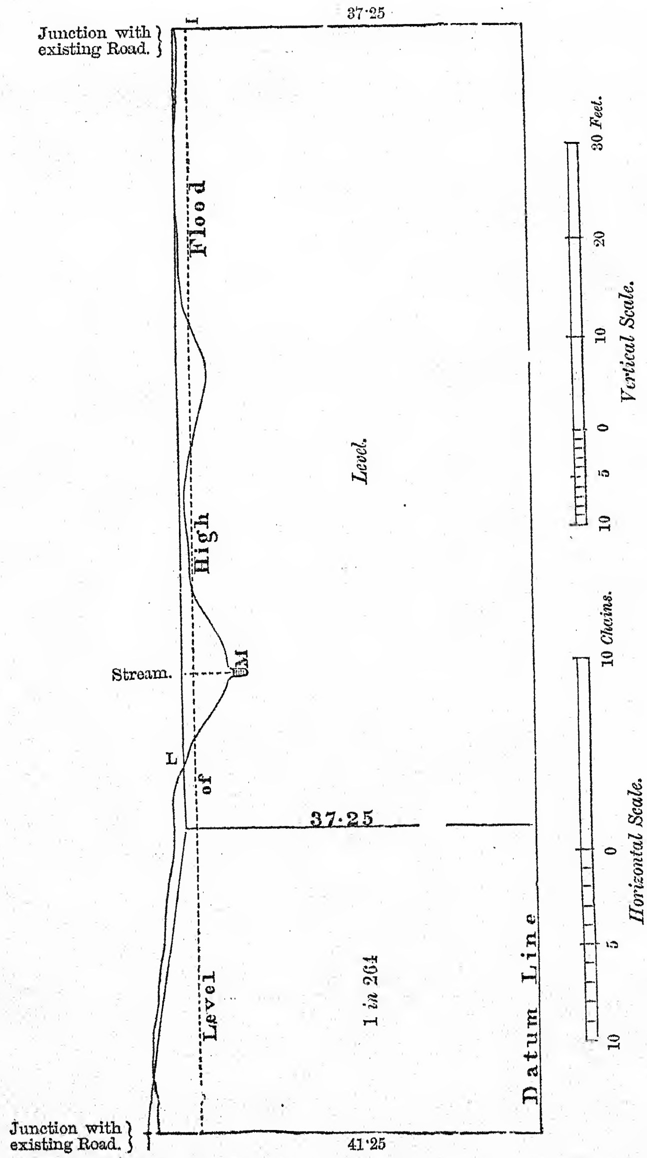


necessity of making an excavation in some other place, to afford the earth for that purpose.

We will now examine the section of the deviation line, and see what improvement can be thereby effected. We must, as before, keep the level of the lowest portion of the road 37·25 feet above the datum; and if we draw a line at that level on the section, fig. 6, we shall find that the quantity of embankment is very much reduced,

and that there will now be no difficulty in adjusting the cutting between H and L, so as exactly to afford the amount of filling required. A few trials will shew that if the line be kept at the same level until within 16 chains of H, and then carried up

Fig. 6.



at a regular inclination, this object will be effected, and that the amount of cutting and embankment will be very nearly equal. This latter will therefore be the line which the Engineer would select as the best; and having done so he would proceed

to mark the course of the road on the ground, by driving a stake into the ground on its centre line at every chain (or 66 feet); he would then take very careful levels of the height of the ground at every one of these points, and at any intermediate point, where any undulation or change of level occurred, and wherever the level of the ground varied to any extent in a direction at right angles with the course of the road, he would take levels from which to make transverse or cross sections of the ground.

From these levels a working section should be made, having a horizontal scale of not less than 5 chains to the inch, and a vertical scale of 20 feet to the inch; a portion of the section plotted to these scales is shewn in fig. 7: the level of the surface of the ground above the datum, at every chain at the points where stakes have been driven into the ground, should be figured in on the section, as shewn in the column A, and the depth of cutting or height of embankment, at the same points, should be given in another column, B. This last column is obtained by taking the difference between the level of the surface of the ground and the level of the road. It will be observed that upon the section there are two parallel lines drawn as representing the line of road: the upper line is intended to represent the upper surface of the road when finished, while the lower thick line represents what is termed the *formation surface*, or the level to which the surface of the ground is to be formed, to receive the foundation of the road: in the section we have made the formation 15 inches below the finished surface of the road, which will therefore be the thickness of the road itself. All the dimensions on the section are understood to refer to the formation level; and the height of the latter above the datum should be figured in wherever a change in its rate of inclination takes place, which should be marked by a stronger vertical line being there drawn, as shewn at C.

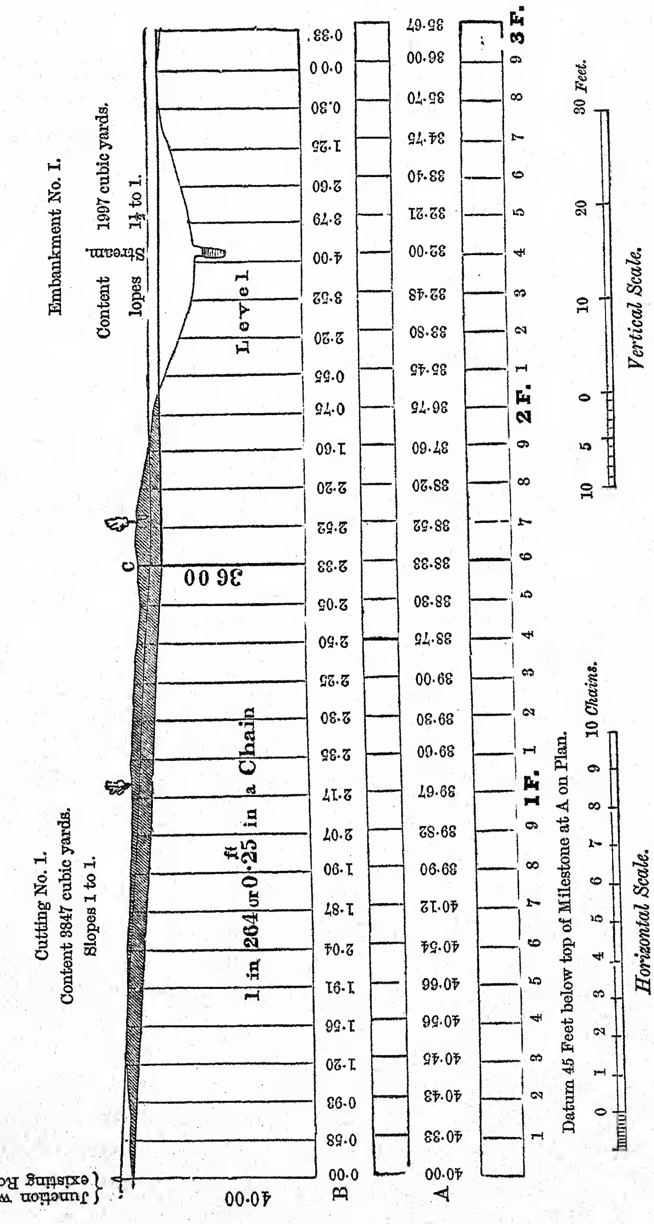
When the cuttings are of any depth, *trial* pits should be sunk at about every 10 chains to the depth of the intended cutting, in order to ascertain the nature of the ground, and to determine the slopes at which the sides of the cutting would safely stand; and also at what slopes the same earth would stand when formed into the embankments. The cuttings and embankments should then be numbered on the section, and the slopes intended to be given to each stated upon the same. The contents of the cutting or embankment, that is, the number of cubic yards which will have to be moved for its formation, with the intended slope, should then be calculated and stated upon the section. The manner of calculating these quantities will be subsequently explained.

Wherever rivers or streams are crossed, bridges or culverts must be introduced, and of these detail drawings should be prepared, and reference made to them on the working section.

A working plan should also be constructed on the same horizontal scale as the section, upon which the position of the centre stakes should be shewn; and on this plan the road should be drawn in of its correct width on its upper surface, and another line shewing the foot of the slopes. The stakes on the plan should be numbered consecutively, to facilitate reference to any part of the line, and the width of land required at every stake should be calculated in the manner which we are about to describe, and entered in a kind of Table, from which the width of land required for the purpose of the road may be ascertained at every chain. We will suppose that in the present case the finished width of the road itself is to be 40 feet, and that an additional 6 feet will be required on each side for the ditch and bank; we have then 26 feet as the side width of the road without any slopes, or where the road is on the same level as the ground, and we shall observe that in the Table in p. 317, wherever there is no cutting or embankment (as at stakes Nos. 1 and 30), this is the width given in the fourth column. To find the heights at the other stakes, we must add to

the constant width (viz. 26 feet) the height of embankment or depth of cutting, as the case may be, multiplied by the ratio of the slope. Thus, in the first cutting, the ratio of the slopes being (as stated on the section) 1 to 1, we have simply to add the depths of the cutting at each stake to 26 feet, and we obtain the numbers given in

Fig. 7.



the fourth column. After the 21st stake we leave the cutting, and the ratio of the slopes then becomes $1\frac{1}{2}$ to 1; we have then to add one and a half times the height of the embankment, and then in like manner obtain the numbers in the fourth column.

No. of stake on the plan.	Depth of cutting.	Height of embankment.	Distance of side fence from centre line.	No. of stake on the plan.	Depth of cutting.	Height of embankment.	Distance of side fence from centre line.
	Feet.	Feet.	Feet.		Feet.	Feet.	Feet.
1	0·00	—	26·0	17	2·33	—	28·3
2	0·58	—	26·6	18	2·52	—	28·5
3	0·93	—	26·9	19	2·20	—	28·2
4	1·20	—	27·2	20	1·60	—	27·6
5	1·56	—	27·6	21	0·75	—	26·8
6	1·91	—	27·9	22	—	0·55	26·8*
7	2·04	—	28·0	23	—	2·20	29·3
8	1·87	—	27·9	24	—	3·52	31·3
9	1·90	—	27·9	25	—	4·00	32·0
10	2·07	—	28·1	26	—	3·79	31·7
11	2·17	—	28·2	27	—	2·60	29·9
12	2·35	—	28·4	28	—	1·25	27·9
13	2·30	—	28·3	29	—	0·30	26·5
14	2·25	—	28·3	30	—	0·00	26·0
15	2·50	—	28·5	31	—	0·33	26·5
16	2·05	—	28·1				

After ascertaining the side widths as above, the next operation is to set out the same on the ground, driving in another stake at every chain at the correct distance on each side of the centre one. A grip about 4 or 5 inches wide should then be cut from stake to stake, so as to mark both the centre and sides of the road upon the ground by a continuous line. The side lines thus set out, it must be remembered, are not the foot of the slopes, but include 6 feet on each side for a bank and ditch; another stake should therefore be driven at every chain, 6 feet within the outer stakes on each side, and another grip cut to mark the foot of the slopes.

A strong post should next be fixed into the ground upon the centre line wherever a change in the inclination of the road takes place (as at the 17th stake in the present instance), upon which a cross piece should be placed at the intended height of the formation surface of the road, and intermediate heights should be put up at such distances as will enable the workmen to keep the embankments to their proper level. In cuttings, pits must be sunk in a similar manner, at certain intervals, to the depth of the formation surface, to serve as guides to the excavators in forming the cutting.

SECTION II.—ON THE SECTION OF ROADS.

Where hills or gradients are necessary, they should be made as easy as possible; and although with all hills a certain amount of additional power must be required to draw a carriage up them, so long as the inclination is within certain limits, the hilly road may be considered as safe as a level one would be. This limit depends upon the nature and condition of the surface of the road, and is attained in any particular case when the inclination of the road is made equal to the limiting angle of resistance for the materials composing its surface,—that is, when it is such that a carriage, once set

* The slopes here change from 1 to 1, to $1\frac{1}{2}$ to 1.

in motion on the road, would continue its descent without any additional force being applied. As soon as this limit is passed, the carriage would descend with an accelerated velocity, unless the horses or other moving force were employed to restrain it; and although in such a case the use of a drag, by increasing the resistance, would in a measure obviate the danger, yet the injury done to the surface of the road by the use of the drag renders it desirable to dispense with it altogether. The following Table, taken from the second volume of the 'Rudiments of Civil Engineering,' shows the rate of inclination at which this limit is attained on the various kinds of roads mentioned in the first column. The values of the resistances on which this Table is calculated are those given by Sir John Macneill, and already quoted at page 305.

Description of the Road.	Force in lbs. required to move a ton.	Limiting angle of resistance.	Greatest inclination which should be given to the road.
Well-laid pavement	33	0° 50′	1 in 68
Broken stone surface on a bottom of rough pavement or concrete	46	1 11	1 in 49
Broken stone surface laid on an old flint road	65	1 40	1 in 34
Gravel road	147	3 45	1 in 15

The Table of Gradients (p. 319) will be found of considerable value in laying out and arranging roads; the first column contains the gradient, expressed in the ratio of the height to the length; the two next, the vertical rise in a mile and a chain respectively; the fourth column, the angle (β, page 306) of inclination with the horizontal; and the last column, the sine of the same angle, which is inserted for facilitating the calculation of the resistances occasioned by the gradient.

We next come to the subject of the width and transverse form which should be given to roads. As regards the first, the width to be given to the road, we should certainly recommend a wide road; it is an error to suppose that the cost of repairing a road depends entirely upon the extent of its surface, and consequently increases just as we increase its width; the cost per mile of road depends more upon the extent and nature of the traffic, and unless extremes be taken, it may be asserted that the same quantity of material would be necessary for the repair of a road, whether wide or narrow, which was subjected to the same amount of traffic; with the narrow road, the traffic, being confined more to one track, would wear the road more severely than when spread over a larger surface; the expense of spreading the material over the wider road would be somewhat greater, but the cost of the materials might be taken as the same. One of the advantages of a wide road is that the wind and sun exercise more influence in keeping its surface dry. The first cost of a wide road is certainly greater than that of a narrow one, and that nearly in the ratio of its increased width.

For roads situated between towns of any importance, and exposed to much traffic, the width should certainly not be less than 30 feet, besides a footpath of 6 feet; and in the immediate vicinity of large towns and cities, the width should be still further increased. No specific rules can, however, be given for the width in such situations; experience will soon show what width is requisite in any given situation.

The form to be given to the cross section of a road is a subject of much importance, and one upon which much difference of opinion exists. Some advocate a considerable curvature in the upper surface of the road, with the view of facilitating the drainage of its surface; while others (and those the majority) are averse to a road

being much curved, for reasons hereafter stated. Again, it is the practice of some to form the road on a flat surface transversely; while others propose giving a dip to the formation surface each way from the centre, on the supposition that the drainage of the road will be thereby facilitated.

Gradient.	Vertical rise in a mile.	Vertical rise in a chain.	Angle (β) which gradient makes with the horizontal.	Sine of angle β.	Gradient.	Vertical rise in a mile.	Vertical rise in a chain.	Angle (β) which gradient makes with the horizontal.	Sine of angle β.
1 in 10	528·0	6·60	5° 42′ 58″	·09960	1 in 60	88·0	1·10	0° 57′ 18″	·01667
,, 11	480·0	6·00	5 11 40	·09054	,, 65	81·2	1·02	0 52 54	·01539
,, 12	440·0	5·50	4 45 59	·08309	,, 70	75·4	·94	0 49 7	·01429
,, 13	406 1	5·08	4 23 56	·07670	,, 75	70·4	·88	0 45 51	·01334
,, 14	377·1	4·71	4 5 14	·07128	,, 80	66·0	·82	0 42 58	·01250
,, 15	352·0	4·40	3 48 51	·06652	,, 85	62·1	·78	0 40 27	·01177
,, 16	330·0	4·12	3 34 35	·06238	,, 90	58·7	·73	0 38 12	·01111
,, 17	310·6	3·88	3 21 59	·05872	,, 95	55·6	·69	0 36 11	·01053
,, 18	293·3	3·67	3 10 47	·05547	,, 100	52·8	·66	0 34 23	·01000
,, 19	277·9	3·47	3 0 46	·05256	,, 110	48·0	·60	0 31 15	·00909
,, 20	264·0	3·30	2 51 21	·04982	,, 120	44·0	·55	0 28 39	·00833
,, 21	251·4	3·14	2 43 35	·04757	,, 130	40·6	·51	0 26 27	·00769
,, 22	240·0	3·00	2 36 10	·04541	,, 140	37·7	·47	0 24 33	·00714
,, 23	229·6	2·87	2 29 22	·04344	,, 150	35·2	·44	0 22 55	·00666
,, 24	220·0	2·75	2 23 10	·04163	,, 160	33·0	·41	0 21 29	·00625
,, 25	211·2	2·64	2 17 26	·03997	,, 170	31·1	·39	0 20 13	·00588
,, 26	203·1	2·54	2 12 2	·03840	,, 180	29·3	·37	0 19 6	·00556
,, 27	195·5	2·42	2 7 2	·03694	,, 190	27·8	·35	0 18 6	·00527
,, 28	188·5	2·36	2 2 5	·03551	,, 200	26·4	·33	0 17 11	·00500
,, 29	182·1	2·28	1 58 34	·03448	,, 210	25·1	·31	0 16 22	·00476
,, 30	176·0	2·20	1 54 37	·03333	,, 220	24·0	·30	0 15 37	·00454
,, 31	170·3	2·13	1 50 55	·03226	,, 230	23·0	·29	0 14 57	·00435
,, 32	165·0	2·06	1 47 27	·03125	,, 240	22·0	·27	0 14 19	·00417
,, 33	160·0	2·00	1 44 12	·03031	,, 250	21·1	·26	0 13 45	·00400
,, 34	155·3	1·94	1 41 8	·02941	,, 260	20·3	·25	0 13 13	·00385
,, 35	150·9	1·88	1 38 14	·02857	,, 270	19·6	·24	0 12 44	·00370
,, 36	146·7	1·86	1 35 28	·02777	,, 280	18·9	·24	0 12 17	·00357
,, 37	142·7	1·78	1 32 53	·02702	,, 290	18·2	·23	0 11 51	·00345
,, 38	138·9	1·74	1 30 27	·02631	,, 300	17·6	·22	0 11 28	·00334
,, 39	135·4	1·69	1 28 8	·02563	,, 325	16·2	·20	0 10 35	·00308
,, 40	132·0	1·65	1 25 57	·02500	,, 350	15·1	·19	0 9 49	·00286
,, 41	128·8	1·61	1 23 50	·02438	,, 375	14·0	·18	0 9 10	·00267
,, 42	125·7	1·57	1 21 50	·02380	,, 400	13·2	·17	0 8 36	·00250
,, 43	122·8	1·53	1 19 56	·02325	,, 425	12·4	·16	0 8 5	·00235
,, 44	120·0	1·50	1 18 7	·02272	,, 450	11·7	·15	0 7 38	·00222
,, 45	117·3	1·47	1 16 24	·02222	,, 475	11·1	·14	0 7 14	·00210
,, 46	114·8	1·44	1 14 43	·02173	,, 500	10·6	·13	0 6 53	·00200
,, 47	112·3	1·40	1 13 8	·02127	,, 525	10·1	·12	0 6 33	·00191
,, 48	110·0	1·37	1 11 37	·02083	,, 550	9·6	·12	0 6 15	·00182
,, 49	107·7	1·35	1 10 9	·02040	,, 575	9·2	·11	0 5 59	·00174
,, 50	105·6	1·32	1 8 6	·01981	,, 600	8·8	·11	0 5 44	·00167
,, 55	96·0	1·20	1 2 30	·01818					

Now it must be obvious to all, that the only advantage resulting from curving the transverse section of the road is allowing the water, which would otherwise collect upon its surface, to drain freely off into the side ditches. It has been urged by some,

that in laying on fresh material upon a road it is necessary to keep the centre much higher than the sides; because, in consequence of the majority of carriages using the centre of the road, that portion will wear quicker than the sides, and, unless made originally much higher, when so worn it will necessarily form a hollow or depression, from which the water cannot drain. Now, it is entirely overlooked by those who advance this argument, that the only reason why carriages use the centre in preference to the sides of a road, is *because of its rounding form*, it being only in that situation that the carriage stands upright: if the road were comparatively flat, every portion would be equally used; but on very convex roads, the centre is the only portion on which it is safe to travel.

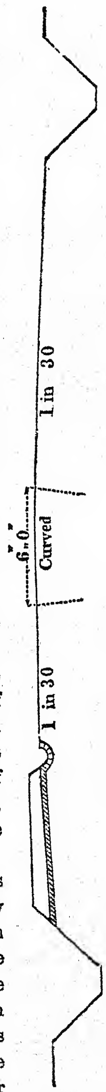
The drainage of the surface of the road is then the only useful purpose which will be answered by making it convex; and even this in but a very imperfect manner, in consequence of the irregularities and roughness found even in the best roads. The surface of a road is much more efficiently drained by a small inclination in the direction of its length than by a much greater transverse slope. On this subject Mr. Walker has very justly remarked,* "Clearing the road of water is best secured by selecting a course for the road which is not horizontally level, so that the surface of the road may, in its longitudinal section, form, in some degree, an inclined plane; and when this cannot be obtained, owing to the extreme flatness of the country, an artificial inclination may generally be made. When a road is so formed, every wheel-track that is made, being in the line of inclination, becomes a channel for carrying off the water much more effectually than can be done by a curvature in the cross section or rise in the middle of the road, without the danger or other disadvantages which necessarily attend the rounding a road much in the middle. I consider a fall of about 1½ inch in 10 feet to be a minimum in this case, if it be attainable without a great deal of extra expense." While, then, the advantages attending the extreme convexity of roads is so small, the disadvantages are considerable: on roads so constructed, vehicles must either keep upon the crown of the road, and so occasion an excessive and unequal wear of its surface, or use the sides, with the liability of being overturned. The evidence of coach-masters and others, taken before the Committee of the House of Commons, and appended to the Report already quoted, quite bears out the view here taken, and shows that many accidents and much danger have arisen from the practice of forming roads with an excessive amount of convexity.—(See fig. 8.)

In making the above remarks, we must be understood as only disapproving of the practice (which has been but too prevalent) of forming roads with cross sections rounding in an extreme degree, and not as advocating a perfectly, or nearly, flat road, as many, who have fallen into the opposite error, have done. We should recommend, as the best form which could be given to a road, that its cross section should be formed of two straight lines inclined at the rate of about 1 in 30, and united at the centre or crown of the road by a segment of a circle having a radius of about 90 feet. This form of section is shown in fig. 8, and the rate of inclination there given is quite sufficient to keep the surface of a road drained, provided it is in good order and free from ruts; if such is not the case, no amount of convexity which could be given to the road would be of any avail, as the water would still remain in the hollows or furrows.

The form of cross section suggested in the figure is equally adapted to all widths of road, as the straight lines have merely to be extended at the same rate of inclination, until they meet the sides of the road.

* Parliamentary Report, 1819, p. 48.

Fig. 8.



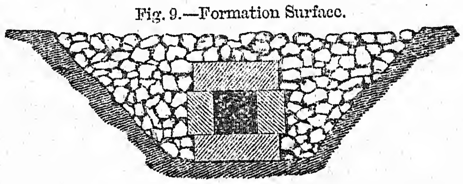
The foregoing remarks apply only to the exterior or upper surface of the finished road; with regard to the form which should be given to the bed upon which the road is to be formed, a similar difference of opinion exists as to whether it should be flat or rounding. In this case we are of opinion that, except where the surface upon which the road has to be formed is a strong clay or other soil impervious to water, no benefit will result, as far as drainage is concerned, in making the formation surface or bed of the road convex. It should be borne in mind that after the road materials are laid upon the formation surface, and have been for some time subjected to the pressure of heavy vehicles passing over them, they become, to a certain extent, intermixed; the road materials are forced down into the soil, and the soil works up amongst the stones, and the original line of separation becomes entirely lost. If the surface upon which the road materials were laid were to remain a distinct flat surface, perfectly even and regular, and into which the road materials could not be forced, then it would be of use to give such an inclination to it as would allow any water which might find its way through the crust or covering of the road to run off to the sides of the same; although, even then, it would have to force a passage between the road materials and the surface on which they rest: such is, however, as we have already remarked, far from being the case; and therefore it must be obvious, except under peculiar circumstances, that no water which had found its way through the hard compact surface of the road itself would be arrested by the comparatively soft surface of its bed, and carried off into the side ditches, whatever slope might be given to it. While, however, we believe that, as far as drainage is concerned, it is useless to form the bed or formation surface of the road with a transverse slope, we should, nevertheless, give it the same, or nearly the same, form as that which we have just recommended for its upper finished surface, with the object of making the two surfaces parallel, and so giving an equal depth of road material over every portion of the road. In this respect we do not agree with some road-makers, who not only recommend a less depth of road materials to be put on the sides than on the centre of the road, but further advise that an inferior description of material should there be employed.

Too much attention cannot be paid to the drainage of roads, both as regards their upper surface and that of the substratum on which they rest. To assist the surface-drainage, the road should be formed with the transverse section shown in the annexed figure, and on each side of the road a ditch should be formed of sufficient capacity to receive all water which can fall upon the road, and of such a depth, and with a sufficient declivity, to conduct the same freely away. When footpaths have to be constructed on the sides of the road, a channel or watercourse should be formed between them, and small drains formed of tiles or earthen tubes (such as are used for under-draining lands) should be laid under the footpath, at such a level as to take off all the water which may collect in this channel, and convey it into the ditch. In the best-constructed roads, these side channels should be paved with flints or pebbles; the drains under the footpath should be introduced about every 60 feet, and should have the same inclination (viz. 1 in 30) as that recommended for the sides of the road: a greater inclination would be objectionable. It is a very frequent mistake to give too great a fall to

small drains, the only effect of which is to produce such a current through them as to wash away or undermine the ground around them, and ultimately cause their own destruction. When a drain is once closed by any obstruction, no amount of fall which could be given to it would again clear the passage; while a drain with a considerable current through it would be much more likely to be stopped from foreign matter being carried into it, which a less rapid stream could not have transported there.

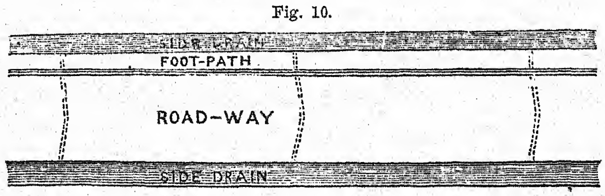
In the case of a road whose surface was drained in the way which we have just described, and which surface was composed of proper materials in a compact state, very little water would find its way through to the substratum; with some descriptions of soil, however, it would be desirable to adopt means for maintaining the foundation of a road in a dry state, as, for instance, when the surface was a strong clay through which no water could percolate, or when the ground beneath the road was naturally of a soft, wet, or peaty nature. Under such circumstances it would be desirable to provide for its proper drainage by a species of under-drainage. As soon as the surface of the ground had been formed to the level intended for the reception of the road materials, trenches should be formed across the road, from 1 foot to 18 inches in depth, and about 1 foot wide at the bottom, the sides being sloped as shown in fig. 9. The distances at which these drains ought to be formed would

Fig. 9.—Formation Surface.



depend in a great measure on the nature of the soil: in the case of a strong clay soil, or one naturally very wet, there should be one about every 20 feet, and this distance might be increased as the ground became firmer or drier. In these trenches, a drain not less than 4 inches square internally should then be formed either of old bricks, drain-tiles, flat stones, or in any other mode used for under-drains, and the remainder of the trench should be filled with coarse stones free from all clay or dirt, in the manner shown in fig. 9. Of course these drains must have a fall given them from the centre of the road into the ditches on either side; an inclination of 1 in 30 will be sufficient. When the road is level in the direction of its length, these drains should run straight across; but on those portions of the road which are inclined the drains should be formed as shown on the plan, fig. 10, somewhat in the form of a very flat V, the point being in the centre of the road, and the drains making an acute angle with the line of the road, in the direction in which it falls: the amount of this angle should not be greater than is shown in the figure.

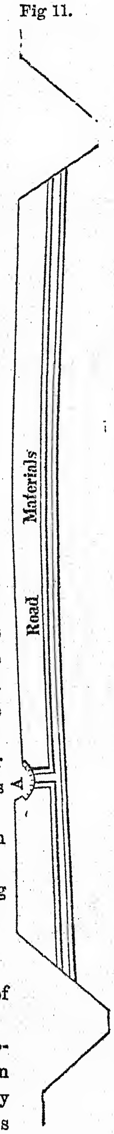
Fig. 10.



When a road with footpaths is under-drained in the manner which we have just described, it will not be necessary to form drains from the side channel under the footpath into the ditch, as shown in fig. 8, but merely to carry up a little shaft, constructed in the same way as the drain, from the drain to the channel, covering the

same with a small grating, to prevent leaves or other substances, which might choke the drain, being carried into it. This method of forming the drains is shown at A in fig. 11.

Fig 11.



SECTION III.—ON THE CONSTRUCTION OF ROADS.

On this subject a great difference of opinion exists. By a few, amongst whom we may mention Mr. McAdam, it has been maintained that a yielding and soft foundation for a road is better than one which is firm and unyielding; and he has gone so far as to say that he "should rather prefer a soft one to a hard one," and even a bog, "if it was not such a bog as would not allow a man to walk over it." * The principles upon which this opinion was founded were, that the road on the soft foundation being more yielding or elastic, the materials of which the covering of the road was formed would be less likely to be crushed and worn away by the passage of a heavy traffic over them than when placed on a hard solid. The contrary opinion is, however, that which has received the largest number of advocates, and is that which we ourselves hold; and we feel assured that there is no more general cause of bad roads than their being formed upon a soft foundation. We would most strongly urge the necessity of securing a firm, solid, and dry substratum for the road materials to rest upon; and we are quite satisfied that, however good the materials themselves may be, and however much care may be bestowed upon the manner in which they are put on, unless a good foundation has been previously prepared, the whole of the materials and labour will be only thrown away. The outer surface of the road should be regarded merely as a covering to protect the actual working road beneath, which latter should be sufficiently firm and substantial to support the whole of the traffic to which it may be exposed. The real use of the road materials laid over it should be only to protect this actual road from being worn and injured by the horses' feet and the wheels, or from the action of the weather. And this lower, or *sub-road*, as it may be called, being once properly constructed, would last for ever, merely the outer case or covering requiring to be renewed from time to time, so as always to preserve a sufficient depth for the protection of the sub-road.

We may very conveniently class roads according to the manner in which their foundations are formed, as follows:

1st, Roads having no artificial foundation, but in which the covering materials are laid on the ground.

2nd, Roads having a foundation of concrete.

3rd, Roads having a paved foundation.

And each of these might be again divided according to the kind of material employed as a covering.

The first of these classes will certainly contain by far the largest proportion of the roads in this country. But it should only be employed in cases where the importance of the road is not sufficient to warrant any large expenditure, and when the amount of traffic to be anticipated is small; for we are certainly of opinion that it is a very mistaken economy which would incur a large permanent annual outlay for repairs, to save in the original cost of constructing the road; and we are satisfied that, in this sense, a road with a paved

* Parliamentary Report, 1819, p. 23.

or concrete foundation will always be found less expensive than one formed without such a foundation.

Where, however, circumstances may render it necessary to construct a road upon the natural surface of the ground, every care should be taken to make it as solid as possible. If the ground is at all of a soft or wet nature, deep ditches should be cut on each side of the line of the road, and cross under-drains should be formed in the manner already described; and where the ground is very soft, a layer of fagots or brushwood, from 4 to 6 inches in depth, should be laid over the surface of the ground before laying on the road materials. In cases of embankments, or where the ground under the road has been recently deposited, the surface should be either rolled or *punned;* that is, beaten with heavy beetles, so as to insure as great a degree of solidity as possible. The same mode of proceeding should be followed even where it is intended to form either a paved or concrete foundation; for, as before remarked, too much care cannot be bestowed on that part of the road.

The employment of concrete composed of gravel and lime was first proposed by Mr. Thomas Hughes, and the following remarks upon its use are quoted from his work on Roads.*

"The use of lime concrete, although an introduction of modern times, and certainly one of rather a novel character, derives its real origin from a very remote period. We have indisputable evidence that the Romans, in constructing their military ways, particularly in France, adopted the practice of forming a concrete foundation composed of gravel and lime, on which also they placed large stones as a pavement. The consequence of a construction so solid has been, that, in many parts of Europe, the original bed or crust of the Roman roads is not at the present day entirely worn down, even after a lapse of fifteen centuries.

"With the view of affording a modern example in which lime concrete has been used, I would refer to the Brixton Road, where a concrete composed of gravel and lime has been recently applied by Mr. Charles Penfold, Surveyor to the Trust. In this case the proportion of gravel to lime is that of four to one. The lime is obtained from Merstham or Dorking, and, before being used, is thoroughly ground to powder. The concrete is made on the surface of the road, and great care taken, when the water is added, that every particle of the lime is properly slacked and saturated. The bed of concrete having been spread to the depth of 6 inches over the half-breadth of the road, the surface is then covered over with 6 inches of good hard gravel or broken stone, and this depth is laid on in two courses of 3 inches at a time, the first course being frequently laid on a few hours after the concrete has been placed in the road. The carriages, however, are not on any account allowed to pass over it until the concrete has become sufficiently hard and solid to carry the traffic without suffering the road material to sink and be pressed into the body of concrete. On the other hand, the covering of gravel is always laid on before the concrete has become quite hard, in order to admit of a more perfect binding and junction between the two beds than would take place if the concrete were suffered to become hard before laying on the first covering. The beneficial effect arising from the practice of laying on the gravel exactly at the proper time is, that the lower stones, pressed by their own weight, and by those above them, sink partially into the concrete, and thus remain fixed in a matrix, from which they could not easily be dislodged. The lower pebbles being thus fixed, and their rolling motion consequently prevented, an immediate tendency to bind is communicated to the rest of the material,—a fact which must be evident, if we consider that the state called binding, or rather that produced by the

* 'The Practice of Making and Repairing Roads,' p. 44.

binding, is nothing more than the solidity arising from the complete fixing and wedging of every part of the covering, so that the pebbles no longer possess the power of moving about and rubbing against each other. It is found that in a very few days after the first layer has been run upon, the other, or top covering, may be applied; and, shortly afterwards, the concrete and the whole body of road material becomes perfectly solid from top to bottom. The contrast thus presented to the length of time and trouble required to effect the binding of road materials where the whole mass is laid on loose, is alone a very strong recommendation in favour of the concrete.

"The experiment of using concrete on the Brixton Road, although not at present on a very extensive scale, has been tried under circumstances very far from being favourable, and on a part of the road which had hitherto baffled every attempt to make it solid. Since the concrete has been laid down, however, there is not a firmer piece of road in the whole Trust; and, from the success of this and other trials made by Mr. Penfold, but which I have not seen, I believe it is his intention to recommend it, in a general and extensive way, to several Trusts under whom he acts."

Mr. Penfold himself states the result of an experiment made by him upon the Walworth Road. "It was raised by 9 inches of concrete and 6 of granite and Kentish rag-stone mixed, and in some parts it was covered by rag and flints. The improvement is so great with respect to the draught, and so desirable with respect to the saving in the annual repair, that the Trust have directed it to be applied to upwards of two miles of road upon which the greatest traffic exists." *

One of the principal advantages attending the employment of concrete as a foundation for roads is, that in this manner a good and solid road may be made with materials, such as round pebbly gravel, which, in any other mode of application, would be but very ill-suited to the purpose, and would form a very imperfect road. And this description of gravel is that which is by far the most frequently met with. The gravel selected for this purpose should be free from any kind of dirt, clay, or other impurity, and should consist of stones and sand, mixed in about such proportions that the latter would just fill the interstices of the former. The gravel should then be mixed with the proper quantity of ground unslacked lime; in ordinary cases five or six parts of gravel and one of lime will be found to answer; after which, sufficient water being added to effect the slacking of the lime, the whole should be quickly, but thoroughly, mixed up, and then immediately thrown into place, and trimmed off at once to the proper form intended to be given to its upper surface; the first layer of broken stones, or screened gravel, as the case may be, should then, as Mr. Hughes directs, be put over just at that period when the concrete is about to set, and which time a very few trials will suffice to determine.

The other mode of forming an artificial foundation, to which we have alluded, was introduced by Mr. Telford, and consists in forming a rough pavement on the top of the formation surface, which is afterwards covered by the road materials. The following is an extract from one of Mr. Telford's specifications for a portion of the Holyhead Road: "Upon the level bed prepared for the road materials, a bottom course, or layer of stones, is to be set by hand, in form of a close firm pavement; the stones set in the middle of the road are to be 7 inches in depth; at 9 feet from the centre, 5 inches; at 12 feet from the centre, 4 inches; and at 15 feet, 3 inches. They are to be set on their broadest edges lengthwise across the road, and the breadth of the upper edge is not to exceed 4 inches in any case. All the irregularities of the

* 'A Practical Treatise on the best Mode of Making and Repairing Roads,' by Charles Penfold, p. 31.

upper part of the said pavement are to be broken off by the hammer, and all the interstices to be filled with stone chips, firmly wedged or packed by hand, with a light hammer; so that, when the whole pavement is finished, there shall be a convexity of 4 inches in the breadth of 15 feet from the centre." *

The stone which Telford employed for this purpose was generally such as would have been totally unfit for most other purposes, both on account of its inferior quality and from the smallness of its dimensions.

In comparing the relative merits of these two methods of forming the foundations of roads, due regard must be had to the nature of the materials found in the locality in which the road has to be formed. Where stone is plentiful and easily procured, the paved foundation would be the best; while, in a neighbourhood where stone is scarce, but gravel and lime abundant, the preference must be given to the concrete foundation.

The foundation of the road having been prepared in either of the modes which we have described, the next proceeding is to form a firm and compact covering to protect the foundation from being injured, and to form a smooth surface for carriages to travel upon. Now, in order to fulfil this double office efficiently, the materials of which this covering is composed should possess the property of becoming quickly united into one solid mass, whose surface should be smooth and hard, and, at the same time, not liable to be broken to pieces, or ground into dust, by the wheels or the horses' feet. All the materials which have been applied for this purpose belong to one of two kinds,—either angular fragments of broken stone of different sorts, or gravelly pebbles more or less round; and it is essential to the formation of a good road that the distinction here pointed out be kept always clearly in view, because a totally different mode of proceeding must be adopted to form a perfect road with these two classes of material. The want of attention to the distinction which we here point out has led to much discussion and misapprehension upon the subject of employing clay, chalk, or other material, as a binding upon roads.

If the materials of which the road covering is to be formed are in angular masses, then no binding of any description is requisite, as it is found that they quickly become united by dovetailing, as it were, amongst each other, and that in a much firmer manner than they would become by the use of any kind of artificial cement.

When, however, the stones, instead of being angular, are round and pebbly, like gravel-stones, it then becomes necessary to mix with them just sufficient foreign matter, of a binding nature, to fill up the interstices between the stones, which otherwise would roll about and prevent the road from becoming solid.

We have, then, two methods of cementing or solidifying the surface of a road: one, by the mechanical form of the materials themselves forming a species of bond; the other, by the use of some cementing or binding matter. And in comparing the relative merits of the two, the preference must certainly be given to the former,—that in which the stones are caused to unite from their dovetail form, without the use of any cementing material. The principal reason for giving this preference is, that roads formed with stones so united are not affected materially by wet or frosty weather; whereas those whose surfaces are composed of pebbly stones united by some cementing material become loose and rotten under such circumstances, from the cementing material becoming softened by the wet, and reduced to a loose pulverulent state by subsequent frost.

The first method, that of forming the road covering entirely with angular pieces of stone, without any other material, was first strongly recommended by Mr. McAdam, and all subsequent experience has shown its superiority over every other which has

* Sir H. Parnell on Roads, p. 133.

been employed. The most important quality in stone for road-making is *toughness;* mere hardness without toughness is of no use, as such stone becomes rapidly reduced to powder by the action of the wheels. Those stones which have been found to answer this purpose best are the whinstones, basalts, granites, and beach pebbles. The softer descriptions of stone, such as the sandstones, are not fitted for this purpose, being far too weak to resist the crushing action of the wheels. The harder and more compact limestones may be employed; but, generally speaking, the limestones are to be avoided, in consequence of their great affinity for water, which causes them, in frosty weather which has been preceded by wet, to split up into a pulverulent state, and destroys the solidity of the road.

Next in importance to the quality of the stone is its proper preparation: this consists in reducing it to angular fragments of such a size that they will pass freely through a ring of 2½ inches in diameter in every direction; that is, that their largest dimensions shall not exceed that measure. The stone, having been thus prepared, should then be evenly spread over the surface prepared for the foundation of the road to the depth of about 6 inches; and the road should then be opened for traffic. In Mr. Telford's specifications, he usually directed that on the top of this coating of broken stone a layer of good clean gravel, about an inch and a half in depth, should be spread before throwing the road open for use. The reason for this practice was, to lessen the extreme unevenness of the surface, and to render the road more pleasant to pass over when first opened. It would be better, however, for the public to put up with the temporary inconvenience of a rough road, because the gravel does a permanent injury to the road, and lessens in a considerable degree the property which the stones possess of uniting into a compact solid mass.

Broken stone, being so superior to gravel for the purpose of road-making, should always be employed where it can be easily obtained. There are, however, many situations in which gravel is the only available material. The quality of gravel varies so considerably, that while some kinds may, when properly prepared, form a very excellent road, others may be entirely worthless: of this last are those kinds of gravel the stones composing which are of the sandstones and flints, for even these last, although hard, are so excessively brittle as to be immediately crushed by the passing of the wheels over them. The gravel, when taken from the pit, should be passed over a screen which will allow all stones less than three-quarters of an inch to pass through it, and the fine stuff, or *hoggin*, as it is technically termed, thus obtained should be reserved for forming the footpaths; the remainder, which has not passed through the screen, should have all the stones whose greatest dimension is more than 2½ inches removed and broken, and it would be desirable that these broken stones should be reserved for the upper layer. In screening the gravel, especially as it first comes out of the pit, a certain portion of loam will generally be found to adhere to the stones, and this should by no means be separated from them; for, as we have already mentioned, although angular broken stones require no extraneous substance to cause them to bind, the case is different with the pebbles, of which most gravel is composed, which require a certain amount of loam, clay, or chalk, to fill up the interstices between the stones, and prevent them from being rolled about, as they otherwise would be. On this subject Mr. Hughes has made some observations so much to the purpose that we cannot do better than quote them: *

"In laying on this upper covering, many surveyors commit a great error in not making a distinct difference between angular or broken stones and those rounded smooth pebbles of which gravel is usually composed. The former cannot be too well

* 'The Practice of Making and Repairing Roads,' p. 15.

cleaned before being laid on the road, because, even when entirely divested of all earthy matter, they soon become wedged and bound closely together when the pressure of carriages comes upon them. But the case is different with the smooth round surfaces of gravel; for if this material be entirely cleaned by means of washing and repeated siftings, the pebbles will never bind, until in a great measure they become ground and worn down by the constant pressure and rubbing against each other. Before this takes place, the surface of the road must be considerably weakened, and will, in fact, be incapable of supporting the pressure of heavy wheels, which consequently sink into it, and meet with considerable resistance to their progress. Under these circumstances, it seems that the practice of too scrupulously cleaning the rounded pebbles of gravel must be decidedly condemned; and the question then arises, to what extent should the cleaning process be dispensed with; or, in other words, what proportion of the binding material found in the rough gravel, as taken out of the pit, should be allowed to remain in the mass intended to be placed on the road? * * * A long course of experience, accompanied by attentive observations on these details in the practice of road-making, has convinced me that it is much better and safer, as a general rule, to leave too much of the binding material in the gravel than to divest it too completely of this substance. When the gravel is placed on a road without being sufficiently cleaned, the constant wear and tear, aided by the occurrence of wet weather, causes the harder material or actual gravel to be pressed close together; and the surplus of soft binding material remaining after the interstices between the pebbles are filled up, being then forced to the top, and usually mixed with water, becomes mud, and, according to the usual practice, should be scraped to the sides of the road. When this has been done, the surface is usually firm and solid, because the hard gravel below the mud has become perfectly bound, without, at the same time, being broken or ground to pieces. Suppose, next, a road covered with gravel too much cleaned, where it is evident that the destruction of the gravel will continue until it becomes broken into angular pieces, and a sufficient quantity of pulverized material has been formed to hold the stones in their places, and thus to effect the binding of the mass. I need hardly say, that the deterioration thus occasioned to the road is an evil of much more importance, and one much more to be avoided, than that occasioned by employing stones not sufficiently cleaned. Regardless of all this, however, it is the practice of many road-surveyors to insist that all gravel, of whatever quality, shall be rendered perfectly clean by repeated siftings, and even by washing, until it becomes entirely divested of all that may properly be considered the binding part of the material."

The gravel, when thus prepared by screening, should be laid on and spread to a uniform depth of not more than 6 inches over the whole road, which may then be thrown open to the use of the public; particular care and attention, however, is required to be given to new roads when first opened for traffic; a sufficient number of men should be employed to keep every rut raked in the moment it appears; and guards or fenders should be placed on the road, to oblige the vehicles to pass over every part of its surface in turn. If these precautions are not taken, years may elapse before the road attains a firm condition; and many roads have been permanently ruined through the want of proper attention when first used. When ruts are once formed, every succeeding vehicle using the road keeps in the same track, deepening and increasing the rut, which in wet weather becomes filled with water, which, having no other means of escape, slowly penetrates the sides and bottom of the rut, rendering them so soft as to be still further acted upon by each succeeding carriage. These ruts once formed, a much larger outlay is required to repair the injury than

would have prevented its occurrence, besides the inconvenience, danger, and expense to the public, in being obliged to travel on a road when in such a condition.

Amongst the substances which we stated might be mixed with *clean* gravel to enable it to bind was chalk. Now, we think it necessary to say a few words on the use of chalk on roads, as some misapprehension exists on the subject, and many roads have been ruined from its improper use. There are two modes in which chalk may be advantageously employed in the construction of roads. It may be laid in the *very bottom* of the road, to form the foundation, *but it must be at such a depth as to be entirely beyond the influence of frost*, otherwise it will quickly destroy the road; for chalk has a very powerful affinity for water, or rather, to speak more correctly, capillary attraction for it, in consequence of which it readily absorbs all the moisture which finds its way through the road covering; and herein consists its value, if judiciously applied, for the water thus absorbed would otherwise have penetrated to the foundation of the road, and rendered it soft. If, however, the chalk be placed within the influence of frost, the water, which is only mechanically held by the chalk, will, in the act of congealing, expand, and by so doing rend the chalk into a thousand fragments, and reduce it, in fact, to a pulverulent state, which the succeeding thaw changes into a soft paste or mud. The other purpose for which chalk may be employed is, as already mentioned, to be mixed with gravel in order to make it bind: in using chalk, however, for this purpose, it should be borne in mind that it is only required when the gravel is perfectly clean and free from other binding matter; the mixing it with gravel already containing sufficient clay or loam is not only useless, but is positively injurious; and even when the gravel is of such a nature as to require being mixed with chalk, great care should be taken not to add too much, for it is not with chalk as with the loam or clay with which gravel is naturally combined; the latter, generally speaking, possesses little power of absorbing water, but the superabundant chalk would soon be reduced to the state of a soft paste by the action of the weather, in the manner which we have just described. Chalk, therefore, if used as a binding material with gravel on the surface of roads, *should be reduced to a state of powder, and should be perfectly and thoroughly mixed with the gravel before the latter is spread on the road.*

We would also remark here, that although we have recommended the use of bushes or bundles of fagots to form the foundation of roads over very soft or boggy ground, they should only be employed in such situations, and at such a depth below the surface, as will insure their always being damp; for when in a situation where they would be alternately wet and dry, they would quickly become rotten, and form a soft stratum beneath the road.

PART II.—MAINTENANCE OF MACADAMIZED ROADS.*

The general extension of railways over all the leading lines of communication throughout the kingdom has greatly tended to withdraw the interest of the public from the consideration that had previously been given to the construction and maintenance of the ordinary roads; a sudden check was put on the progress of improvement, and the systems for those important operations remain where they were some fifteen or twenty years ago, when they had by no means arrived at perfection.

It is not assumed that any novelty is to be introduced into the old *principles* for the maintenance of macadamized roads, but the extent to which it is considered that they ought to be carried out is not recognized, or, at least, practised.

* By General Sir John Burgoyne, Bart., G.C.B.

The chief features of proposed improvement are—

1st, The keeping the road *perfectly clear* of dust, dirt, or of any unconnected matter over the crust of consolidated broken stone.

2nd, Minute repairs to the surface, in small patches, immediately on the appearance of any want of form or substance.

Previous to entering into the question of maintaining a road, we ought to suppose it to be, in the first instance, in a proper state.

There are two very important requisites for a road, without which it ought not to be considered, if a new road, as completed, or, if an old one, as efficient; one of which is generally much neglected, and the other entirely. The one is thorough drainage; the other, the consolidation, as part of the work, of any great mass of new-laid stone.

It is very rare, indeed, that a road is thoroughly drained. If it has a longitudinal drain on each side, in which the water does not remain at any time standing so high as the lowest part of the cross section of the road, it is considered to be adequately drained; but it is suggested that under many circumstances it may fail to be so, and that instances may be constantly seen where such drainage is quite insufficient, as in the following cases:

1. Where along flat ground, the water remains in the drain for lengthened periods, up to within a few inches of the level of the road, the moisture will soak through, be retained under the surface of the road, and cause it to be soft and heavy.

2. Where the road is wide between these drains, viz. from 30 to 60 feet, or upwards, and the soil at all retentive of moisture, the wet will be long in passing off.

In the drainage of lands for agricultural purposes, on the system practised by Mr. Smith, of Deanston, which is generally received as judicious, 18 feet is a usual distance between his covered drains, while 30 and 40 are extreme distances; and, certainly, it is far more important to under-drain a road.

3. If there are springs, or any degree of filtration of water not cut off by the side drains, in the bed of the road, theory says, and even specifications require, that they should be drained off, but in practice it is seldom attended to.

4. The flatness that is now given to all roads is such as will not admit the water to run off them, unless it falls in very large quantities, and then only partially, or unless the road be very smooth, hard, and perfect in shape. Even the slight curve that is required is very seldom preserved in the habitual maintenance of the road, certainly not in the firm part of it, if any can be called so.

If a road is to be kept in the ordinary inefficient condition, it would be decidedly better to give a greater curvature to its cross section than usual, notwithstanding the evils attending it.

5. All the water that falls on the sheets of loose broken stone, which always lie a considerable time before they are consolidated, disappears, it is true, from the surface, but soaks on to the under stratum, and is by so much the worse, as it is in some degree retained by the consistency of the hollow in the remaining crust of the road.

6. It is rare that water has so free a passage as it ought from the water-tables, through the footpaths or other obstructions.

7. Lastly, it is not uncommon for the gullets for passing small watercourses under the road to be quite insufficient in number or dimensions.

These defects are almost universal: to remedy them thoroughly, that is, to a degree far greater than is now usually thought to be at all necessary, would cost much less than the wear and tear occasioned by their existence; and, indeed, without their being *thoroughly* provided against, no labour or expense will keep the road in a first-rate degree of perfection.

It is this, perhaps, more than any other circumstance, that renders it most difficult by any expenditure to keep a macadamized roadway in the greatly frequented streets of large towns in any sound state during a continuance of very wet weather.

With regard to the second requisite, namely, the consolidation of the broken stone on new roads, (or in cases of extensive repairs,) before they are given up for the general traffic, no road ought to be considered to be finished until thoroughly rolled, that is, to a degree that will admit of horses in draught trotting over it without much extra exertion.

As this is seldom if ever attended to, the propriety of its adoption requires some distinct explanation and arguments, which will be found at the end of this article.

The great advantage of maintaining roads in good condition, as a measure of *economy*, has frequently been adverted to, but cannot be too often repeated or too strongly enforced, particularly since it is little attended to in practice.

Without going into the question minutely, perhaps the following, as a single illustration, will not be considered overstrained :

Suppose the work of every horse on any given road be calculated at twenty miles daily journey upon it, and that the services required be regulated by the number of horses applied, it is probable that the difference in the state of a road that would enable four horses instead of five to do any given amount of work would not be so great as most persons might imagine.

The calculation may be made in various different ways ; distances traversed, or loads conveyed, or rates of speed, may be varied according to the goodness or defects of the road ; the supposed *result*, however, by any mode of reasoning, is, that four-fifths the amount of animal labour should be able to do the work in one case, that would require one-fifth more in the other.

Supposing the number of horses employed to be equal to an average of eighty daily, over twenty miles of the inferior road,* then sixteen horses (or one-fifth) might be spared if the road were improved to the condition contemplated on the above calculation.

Suppose also the value of each horse to be estimated at £45 per annum for his purchase, feeding, care, harness, &c.,† there would be an available amount of £680 per annum for the improvement and maintenance of this twenty miles of road at its superior state, or £34 per mile.

If it could be shown that an increased expenditure on the road, not exceeding that amount would have the effect of placing and maintaining it in the superior condition, it must decidedly be true policy that it should be incurred, not only on account of the one ingredient of reduction of animal labour, but on many others on which it is not easy to put a money value,—such as wear and tear of carriages and harness ; greater degree of lightness and ease that may be given to the carriages ; saving of time by increased degrees of speed that would be adopted for traffic of all kinds, but particularly for passengers ; greater freedom from mud or dust ; reduction of cruelty to animals, which by no process can be so great on a good as on a bad road ; improved business in the district, and increased traffic that would be brought on the road by the additional facility and comfort it afforded, with very many others.

This argument has reference to the question as regards the public generally, with-

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* Equivalent to the work of a single horse over 1600 miles, including the amount traversed by every horse over every part of this 20 miles.

† It is submitted that £45 per annum can hardly be deemed high ; it would probably amount to that average by the addition of a horse to every carriage ; but when it is considered that most of them are single-horse vehicles, each additional horse in those cases would require an additional carriage and driver.

out consideration of what parties are to pay for the expenditure, or what parties are to receive the benefit,—a consideration that, unfortunately, frequently leads to many impolitic proceedings.

In Ireland, for instance, where the roads are maintained by county assessment, the amount of funds granted has chiefly reference to the weight of the tax, and not to the necessity of the case, or the indirect advantages to the community from good roads.

The first principle to be established should be the most beneficial and economical system for the country generally, and afterwards to regulate the just apportionment and the manner in which the necessary funds are to be raised.

It is not the object of this article to go into the question of how that is to be done, but it may be stated *en passant* that the turnpike system, on the fallacious reason of *those who use the road paying for it*, is considered to be by no means judicious or equitable.

In treating of the condition of a road, the present intention is merely to consider how to preserve its surface, without reference to any question of how it may have been carried through the country, or of its hills, &c.,—matters that have more relation to construction than to maintenance.

A road in superior condition is assumed to be one that has always a hard and even surface, with curvature just sufficient for the water to run off, without even small hollows in which it will lodge, without mud in wet weather, or dust in dry, and at no time with extensive patches of the usual sized broken stone newly laid upon it.

The inferior road is precisely the reverse of this in its qualities, but the degree of inferiority cannot be very accurately defined: it may, for the purpose of this argument, be considered such as would, generally speaking, be termed, more or less, a heavy or rough road.

The time when the relative condition of roads is most clearly to be perceived is in very wet weather; the good will then be still quite hard, with no inequalities, no dirt, no puddles; it will be as a good road in summer recently watered.

The inferior will be muddy, in numerous puddles, rough, or soft and heavy.

It has been endeavoured to be shown that it would be good policy and economical to expend a considerable *additional* sum annually in improving and maintaining the road in the superior manner, if not to be effected without such extra expenditure.

A road *must* have at least three or four inches of stoning upon it, or, if not very firm, wheels will in parts cut down to the subsoil, and it will be impassable.

As the stone, therefore, is worn down to dust or mud, it *must* be renewed in at least equal quantities.

This is all, therefore, that is absolutely necessary to enable carriages to make use of it; and by an erroneous inference, which it would appear, judging by the ordinary course of proceeding, is general, it is considered that the cheapest mode of maintaining a road in a condition to be merely passable, is to do no more than lay down stone along it, just before it arrives at its minimum thickness.

It seems also to be considered, that whatever improvement is made beyond that state, in the goodness of the road, as a measure of convenience, or for the economy of the working power on it, must be at the sacrifice of some direct increase of expense upon the road.

There is, however, great reason to believe that by a proper system the greatest improvements might be made at *very little, if any, increased outlay.*

It would be manifestly a subject of great importance to prove and establish such a position.

On a thoroughly good road, the wear is even, gradual, and *very slow;* the carriages

work indiscriminately over every part; but such a condition must be narrowly watched, for if left to itself, slight inequalities are formed, each of which tends to a more rapid wear of the road; and in proportion to the length of time that these are allowed to continue and increase, and the less frequent and more extensive are the repairs, by so much will be the injury done by each carriage: thus, in the first case, where the traffic of one week may do, in a given distance, ten shillings' worth of injury, in the worst of the latter it may do damage to the value of twelve or fifteen; if, therefore, it can be maintained at once in the better condition at the higher rate, though the ultimate expense is the same, yet we have the good road instead of the bad.

Independent of the constant perfect efficiency of the drainage, and that a good form of cross section be preserved at every application on the surface, there are two leading operations to be regulated,—namely, the removal of the produce of the wear, in the shape of dust or mud, and the application of fresh material to replace the loss.

First, with regard to the dust or mud, arising from wear or other causes. In roads that are much neglected, this waste matter is never removed; in such cases, unless under very favourable circumstances of original good construction, very perfect drainage, great exposure to the sun and wind, and small traffic on it, the road will be very dusty in dry, and very muddy in wet weather, all which not only tend to make it heavy to the draught, and to create inequalities, but to increase greatly the grinding operation of the wheels, and consequently more rapidly to consume the material.

From such a state of absolute neglect, various gradations may be adopted; first, to a partial removal, at long intervals of time, when there shall be a great accumulation; thence to a more frequent removal, up to the best system, namely, that of constant attention, and *an entire prevention of any perceptible collection.* In the first case, scrapers of different materials and forms are used, or shovels and birch brooms, till, in the latter, the broom alone may be sufficient.

The waste matter from the wear of the road (always injurious if left upon it) may be removed as dust or as mud:—in the former state, however, with much greater facility and advantage. As dust, it is removed before it has done much injury; it is lighter and easier to collect; a broom, which is the implement to be used, does not derange the surface, as a scraper may in the removal of mud;—the scraping away of mud will leave much that will form dust, while sweeping away the dust will leave nothing for mud.

Unfortunately, however, the climate of England and Ireland, by the proportion of wet as compared with dry weather, would not admit of this removal of dust to any very great extent; still the principle would be adhered to as much as possible, and at all events no accumulation of either dust or mud should be allowed.

The *constant* sweeping away of the dust or soft mud may be deemed the prevention of evil; the occasional scraping away the stiff mud in quantities, the remedy for it.

The manner of supplying the material for preserving the necessary thickness for the crust of a road, will also admit of great variation from the worst system, which is that of waiting till the surface has lost its shape, is covered with mud and pools of water, to which a thick covering of stone, broken to the usual dimensions, is applied over extensive distances, and there left to be worn down by the carriages that casually pass it.

This necessarily produces very heavy draught,—chance of injury to horses' feet,—a very slow formation and consolidation, a great deal of displacement of material, and extra grinding and wear and tear; and thus the road is periodically rendered almost

unfit for transit by the very operation that is called its repair, and ultimately remains a mis-shapen fixing of not half the quantity laid down.

On that system improvements are introduced by more frequent patching in smaller quantities at a time, up to that which may be deemed the most perfect, namely, a constant watching, and the application of *very small patches of stone broken fine*, carefully supplied to the small hollows, as they shall successively be formed, and to places where the shape or strength shall be deficient, these parts being loosened with a pick, and the fresh material rammed down* into them, and attended to carefully till finally consolidated.

It is very evident that instead of all the grinding and crushing of the material which attends the passage of wheels over the soft rough road, the friction and consequent wear on that which is perfectly even and hard must be *most trifling*.

Under the system here recommended as the best, there will be, no doubt, some additional manual labour requisite *on the road*, but at the same time a most decided saving of *material* and in the carriage of it; and in cases of tolerably frequented roads, or where material is distant, and therefore costly, perhaps it may be said generally, the saving on that item will be greater than the extra expenditure on the other; thus obtaining an *absolute reduction of outlay* to procure the perfect road, and what is of advantage in almost every country where it can be effected without extra expense, increased work for the labouring population of the vicinity; that is, the substitution of manual labour for the employment of material and animals.† It may almost be asserted, that under a thorough good system, the better the road is, the less will be the outlay upon it.

Many of the above remarks have been suggested by some very interesting papers written by Mons. L. Dumas and other French engineers of the Corps des Ponts et Chaussées.

They state many facts which establish in a great degree the gradual improvement of system and the soundness of these principles.

The following took place with respect to the high roads (Routes Royales) of the Département de la Sarthe, somewhat less than 250 miles in extent :—

		Per Mile.
In 1793 a demand was made to put them in complete order .	£15,280 or	£60
In 1824 the demand was about	9,000 ,,	36
In 1836 ,, ,, ...	7,760 ,,	31
In 1839 ,, ,, ...	6,640 ,,	26

And the roads have become better concurrently with the reduction of cost in maintenance, from being in 1793 in deep ruts, to 1839, when they were in very good order.

Part of the great road between Lyons and Toulouse, till 1833, was always in a *dreadful state*, and yet cost habitually about £110 per annum per English mile for maintenance, when M. Berthault Ducreux introduced a system of patching instead of general repairs; since when, the road was gradually improved, till it was in a *very good state*, and the annual expense reduced by £13 or £14 per mile.

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* Loosening the surface with a pick whenever new material is laid on is quite necessary when a road is *firm;* those who argue that it is unnecessary or wrong, must refer to roads that are soft, in which case it will be more readily pressed into it, and then also the stone may be broken larger.

† It is not meant to convey the idea that the procuring of material and even the carting is not attended also by a great proportion of manual labour, but to a smaller amount in equal expenditures, and much of it to a different and superior class.

Another instance is quoted, where, prior to 1837, the average amount of broken stone laid on 33 miles of road was 6000 cubic yards; under the improved system in 1837, 5000 cubic yards were applied; in 1838, only 1350 cubic yards; and in 1839 none.

This last case, however, may have been one of those where they have found in France the system of heaping masses of broken stone as the only remedy for a degraded state of road had led to a great superfluous accumulation of material, in *many* instances amounting to 12 and 15 inches, and in some actually to 3 and even 4 feet. In such cases they have subsequently gone on for years attending to drainage, form, and keeping the road clean, and applying very little or no fresh material for the whole time.

In another instance the cost has been as follows:—

Year.	Expenditure.		Total.
	Material.	Road Labour.	
	£	£	£
1830	548	166	714
1831	563	188	751
1832	496	151	647
1833	500	167	667
1834	438	177	615
1835	398	145	543
1836	380	160	540
1837	360	178	538
1838	180	233	413
1839	250	300	550

In 1837, when it was taken up on the new system, the road required considerable improvements; in 1840, two-thirds of it were in perfect condition; and whenever the whole might be re-formed, it was calculated that from £400 to £440 would keep it perfect.

But more complete illustrations are to be found in the road from Tours to Caen, in La Sarthe, which was in 1836 in so bad a state that an official report of 3rd May of that year announced, that without a special credit of £2000 towards it, and *a great additional provision of material*, there was danger that it would become impassable: in January, 1837, it was put under the charge of Monsieur Dumas.

The expenditure upon it for some years before and after that period was as follows:—

Year.	Expenditure.		Total.
	Material.	Road Labour.	
	£	£	£
1832	872	195	1067
1833	708	205	913
1834	745	236	981
1835	671	280	951
1836	684	293	977
1837	584	504	1088
1838	445	456	901
1839	412	420	832
1840	271	392	663
1841	163	445	608*

* It is worthy of remark, in the above Tables, how by the improved mode there is an increase of road labour, and a reduction in consumption of material.

In August, 1838, this road was reported to be in a very good state, and since then it has become better and better.

In 1834, the mail required always five horses, and the road was then so bad that the postmaster lost eleven by the hard work in one year. In 1837 it required four and five horses. In 1838 the number of horses was reduced to three; and in 1843 there were only two of middling quality, and the postmaster lost none from that cause.

In this same district, in consequence of the improvement of these roads, since 1839, a number of lighter public carriages has been established; they have now (1843) four wheels, are drawn by one horse, carry nine passengers, and go between seven and eight miles an hour: previously, the carriages for the same number of passengers had two wheels, two horses, and went slower.

There are somewhat less than 45,000 miles of high road in France, over which it was reckoned in 1835 that seventy-five horses in draught passed daily, exclusive of passenger carriages, each horse drawing an average of one French ton (1000 kilogrammes, equal to about $19\frac{3}{4}$ cwt. English) besides the carriage, and the cost of drawing of each ton per league (about $2\frac{1}{2}$ miles English) was reckoned to be one franc (10*d.*). This would make the expense of the draught of merchandise over the high roads in France between 20 and 21 millions of money per annum.

These French Engineers calculate that there might be a saving of at least one-third, say of £7,000,000, to the public, by maintaining the roads in the best possible condition, from that on which these calculations were made, which they affirm may be done without a fraction of increased expense; on the contrary, by a reduction in the expenditure on road repairs.

So great an effect is not to be produced in Great Britain and Ireland, because the high roads are not in so bad a condition as they were in France when this calculation was made; nor is the accumulation of broken stone so great as to admit of abstaining altogether from the application of fresh material for a considerable period, as appears to have been very much the case in that country on the introduction of this improved system.

But principally there is an advantage there in respect to climate,—the wet weather being only calculated at one-third of the days in the year, and the dry at two-thirds; nor is the material perhaps relatively so cheap as in Great Britain, and consequently the saving on that item would be less in this country.

Still there is very great room for improvement in the system of maintenance of roads in the British Islands from even the best now practised, which is by frequent patching, to that of *constant* attention, determined prevention of the collection of dust or mud, and the application of finely broken stone, carefully blended in with the old in small patches on the *first appearance* of inequalities or deficiency; and if the variable and more damp character of the climate is unfavourable to the wear, and to the sweeping away of the waste matter in the shape of dust, it affords the advantage at least of presenting greater opportunities, even in summer, of applying the broken stone, which cannot be done during dry weather without artificial watering.

The principle of *unceasing* and minute attention to the road requires a different mode of proceeding from that of occasional working at intervals.

It will require men on constant duty for every part of each district.

In England, men have been employed on this principle, called *milemen*, and with great success.

In France it is very general, if not universal; they are called *cantonniers*.

Such men must reside in the immediate neighbourhood of their district, and, if possible, they should be very near the middle of it.

The milemen in England seem to be considered generally as a class of gangsmen, and have labourers under them in proportion to the work that may be required at different periods.

In France the cantonnier frequently does all the work, except on very special cases of need, and some importance is attached to allotting such portion of road to each man as he may be able to attend to by himself, and as will give him full employment.

The advantages they propose by this is to render the expense more regular,—to encourage a spirit of pride and emulation among them, and thus stimulate their ingenuity and exertions; the entire and undivided responsibility resting with each.

What with attention to drains, to the shape and trimming of the road, to the removal of loose stones, and to very frequent sweeping, preparing material after it may be brought to the places of dépôt, and applying it where needed (which latter must be done in wet weather), it has been found that the work may be made constant and generally pretty regular throughout the whole year.

Under the French system the extent of road given to each man must be nicely regulated, so as to give him full employment, and yet not more than he can perform; and this adjustment is one of the greatest difficulties in the system, as the efficiency and economy of the maintenance will greatly depend upon it: if the district be too large, the man cannot do justice to it; in that case, some mud, dust, or loose stones must be admitted, or inequalities allowed on the surface; the question will be how much it ought to be, and the regulation becomes indefinite and incomplete: if the district be too small, it will not be easily detected, as he will hardly confess it, or perhaps even be aware of it.

The object of the preceding remarks is to endeavour to establish—

That to obtain the best of roads requires much more *constant* attention than is now bestowed upon them; and that there is great reason to believe, that generally this may be done without incurring any additional outlay.

That the drainage ought to be more effective; and after that is provided for, the two leading operations requisite are, 1st, Perfect cleanliness—that is, the removal of all dirt from the road before it has time to collect in any sensible degree; 2ndly, The patching of every inequality, so as to preserve the surface perfectly smooth, and to provide for the waste in small quantities, and by material of the very best quality that can be had, immediately that the most minute want is perceived.

If a road that has four inches or more thickness of broken stone upon it is in bad condition, the proper process will be, not that ordinarily pursued of immediately laying two or three inches of fresh material along its centre, but to commence cleaning it of the dust or mud, then to make good the surface to an even and proper shape, pick up all the little hollows, fill them with patches of broken stone, and to pay subsequently constant attention to those same operations.

OBSERVATIONS AND EXPLANATIONS.

The dirt will be removed chiefly by the broom, and will be far more valuable as a manure for land than what is now obtained. By removing it rapidly, and keeping the surface even and firm, there will be very much less of the stone-dust, which, except in limestone, causes poorness in the manure; consequently it will consist chiefly of the dung, dead leaves, and other extraneous matter deposited upon it, which is in much greater quantity than would generally be supposed. This may be illustrated by the dirt that is collected, where there is much traffic, even on the best pavements, the wear of which is in this respect as nothing.

It is well known that the more clean and free from dirt the broken stone laid on

roads is, the better: by laying it down in repairs on a dirty road, you are manifestly infringing this rule, and mixing up with it a quantity of matter that is thus acknowledged to be prejudicial.

The employment of the toughest and best material for the broken stone is of far more importance on this than on any other system; the reduction in the quantity consumed will, under most circumstances, make up for the excess in its price; and that reduction essentially lessens the amount of *every species* of the work.

One great advantage of a hard even crust at all times is, that it will bear far greater weights with equal thicknesses. An instance is mentioned, in one of the French works, of a load of nearly fifteen tons being drawn by thirty-three horses on a carriage having wheels of $6\frac{1}{4}$-inch tires, over three quarters of a mile of a good macadamized road of only four inches thickness of metal, without leaving any perceptible trace; therefore, a perfect road, kept to an habitual thickness of eight or nine inches, will not only be sure to be perfectly substantial, but will in times of need bear a considerable period of wear and tear without fresh supplies of material; and the reduction being very gradual, there will be a power of materially regulating the labour connected with that supply by the demand for it. Thus at present, the given quantities of stone must be provided throughout every year and at precise periods, whereas by the proposed mode, the supply may be reduced in seasons, or for a whole year, when labour is plentiful, and increased when there happens to be distress for want of work.

Where roads are to be kept in such perfect condition by minute attention over *every part* of the surface, it becomes of much more importance that they should not be wider between the water-tables than may afford ample space for the traffic; and not widening out irregularly, and without any necessity, as may sometimes be witnessed.

It must not be assumed, in cases where a road is greatly improved, and the outlay on it may remain the same, that no saving is effected; because a necessary consequence of an improved road will be increased traffic, and therefore the expenditure will be less as compared with the service it renders.

The cost, however, of maintenance of roads, as compared one with another, will by no means be always in proportion to the amount of traffic; among other matters that will influence it may be—nature of soil, hills, relative level of road with the contiguous land, greater or less exposure to the sun and wind, quality and price of broken stone, &c.

With reference to the regular roadmen, as proposed, some remarks occur.

They may be selected from the most diligent, trustworthy, and intelligent labourers; and as they should be retained as a constant establishment, and on somewhat superior allowances to the ordinary labourer, the employment will create a source of encouragement for that class.

The work, though constant, will be of a lighter, more cleanly, and healthy character than that of the ordinary day-labourer on the roads at present, who is frequently day after day wading in deep mud. In France they describe having some of these constant men (*cantonniers*) at eighty years of age, in employment on reduced districts; indeed, much of the work is so light that even women or children may assist at it.

The length of road under charge of one man may vary under ordinary circumstances from one to three miles; in narrow roads of very small traffic, this length may be increased, and on great outlets to populous places, no one man could probably undertake anything like one mile.

Experience in France seems to show that one man can sweep in dry weather between

260 and 270 yards of road of from 15 to 18 feet wide in a middling state, and double the distance if in a perfect state: suppose his charge to be one mile and a half, he could therefore sweep it all over three or six times per month, if the weather was dry, and he had nothing else to do; in general, however, one or two complete sweepings per month was found to be adequate.

Something may be said on the manner of operating on the system here recommended, and on some of the tools that have been found useful in this mode of maintenance.

Every little inequality or hollow in the road is to be repaired very early, and while it is small. It may be observed that these are always of a round or oval form, and therefore the square or rectangular patches which the workmen are usually inclined to make of them are wrong, and a waste of material.

Picking up the surface before the patching with new material is only done to a depth of about half an inch, rather more at the edges than in the middle, and if some of the finer particles can be raised and laid over the broken stone as blinding, the effect will be improved.

The stone for patching should be broken fine (say to $1\frac{1}{4}$, or at most $1\frac{1}{2}$-inch ring); of those broken to dimensions not exceeding 2 inches, one half or more will be sufficiently small, and the rest can be reduced.

The use of a rammer and mallet is of great service on new-laid patches of broken stone. A rammer weighs from 11 to 22 lbs., with a surface of about 6 inches in diameter. This is applied to the new-laid material, and gives it a certain degree of consistence; the impressions made by the horses' feet or by wheels are *rammed* to an even surface again, which is far better than *raking* over the inequalities; if the fall of the rammer is not sufficient, a mallet of similar weight and surface enables a greater force to be applied. Whether rammed or not, another description of mallet or flattener is very useful; it is of from 18 to 22 lbs. in weight, with a surface of 12 or 13 inches diameter.

These tools, though inferior to the roller, have been employed very successfully in the consolidation even of new roads, thus: after the broken stone has been laid in proper shape, a very slight sprinkling of gravel, or other fine clean small stuff, is spread over it; as the carriages pass, the rammers are used to level the ruts and traces of horses' feet, &c., instead of raking. In this manner roads have been brought into a firm, smooth state in two months, when six were consumed to produce the same effect where not rammed.

Whenever loose stone is to be consolidated, it is absolutely necessary that it should be wet; if the weather is dry, there should be artificial watering. Even in patching the road, the same should be attended to, if possible; at least, the consolidation will never take place until there is wet.

After a long period of dry weather, even good roads will begin to loosen; watering and the rammer or flattener will quickly put them to rights.

The dirt of a road is removed with most facility as dust; the next most favourable state is as very liquid mud, because, in either case, a broom is sufficient for collecting it.

The best qualities of brooms for different circumstances will be readily ascertained by experience, and, no doubt, means will be readily found to make brooms of considerable width, say two or three feet, either to be worked by hand in the usual way, or on wheels in order to facilitate the operation.

The collection of dirt swept up must be very carefully packed on the side of the road, in a manner to form no impediment to the water draining off from the surface, and should be carried away altogether *very soon*.

ON WATERING ROADS.

The laying of dust by watering, as is the usual practice, instead of removing it, is a pernicious and expensive system.

In the first place, it requires the frequent application of large quantities of water, and forms at once a mass of mud, as may be frequently witnessed : this mud tends to a more rapid grinding and wear of the surface while it lasts; but during very dry weather it soon dries up, and requires the operation to be again repeated. It is, in fact, instead of removing the evil, substituting another for it, and one which requires to be constantly renewed.

If the surface were hard, and the dust carefully removed, a very light sprinkling of water might be applied to much-frequented roads in dry weather, as a luxury.

It will be said, perhaps, and may be acknowledged, that sweeping up great quantities of dust would, in itself, be an intolerable nuisance, but the object is to prevent any great accumulation, by commencing as soon as it begins to form ; and the sweeping may be done either in conjunction with a slight watering, or very early in the morning, when there is little traffic, and little to be disturbed by it, and when the dew of the night will tend to prevent its rising so much.

Where watering is practised, there are few cases where a very great saving in that costly operation might not thus be effected, and applied to the removal of the dust or mud.

ON MACADAMIZED ROADWAYS IN LARGE POPULOUS TOWNS.

There may be doubts as to the policy of macadamizing streets of cities and populous towns, on account of difficulty of perfect drainage ; frequent wants of the full, free effect of sun and wind ; and impediment, by reason of the constant great traffic, in the way of the necessary perpetual attention to the removal of waste matter and application of material.

It is apprehended that a *perfect* pavement is eventually cheaper, and altogether preferable, excepting in one particular, namely, the noise; the wood pavement is subject to inconveniences that have hitherto been insurmountable.

Dublin may be given as an instance of the effect of macadamization in much-frequented streets.*

The superintending engineers there appear to pay every proper degree of attention to their duty ; the ordinary proceedings are practised, and yet it must be confessed (1843) that the roadways are in a most unsatisfactory condition, and anything but fulfilling the requisites of good roads, namely, being *clean*, *hard*, and *even*, at *all seasons*. On the contrary, they are in winter, or wet weather, habitually covered with mud, and in summer they would be as deeply overwhelmed with dust, but for profuse watering ; they have, in fact, at all times, a thick coating of dirt on them, mixed up with the broken stone of their substance, to the very foundation.

In winter, a large expense is incurred in scraping and removing mud ; but it is not sufficient to keep it under in any essential degree. The nature of the work may be judged of by the very name which is given to it, '*Scavengering*.' In fact, the men are nearly ankle-deep in mud, as they move to and from the line of stuff they are scraping up.

A small portion of the scrapings is sold as manure, at 6*d*. and 1*s*. per ton; it is that chiefly which is taken from the few paved streets; the remainder (from the

* Frequent allusions are made to Ireland, because this article was originally drawn up during a service in that country.

macadamized streets) is carried away and deposited as spoil at the expense of the Paving Board.

The watering, though not universal, is applied to almost all but small streets. It is paid for in a separate rate by the inhabitants of the streets who apply for it.

In summer, the roadway, excepting by being watered, is left very much to itself, the only other operation being to lay down occasionally patches of broken stone where the surface gets so bad that it cannot be delayed.

The result of the laying down the stone at that season (and sometimes necessarily in very dry weather) occasions great inconvenience and waste. The horses and carriages, when forced upon it, suffer in consequence. The material will not, in spite of the watering given to it, consolidate for very long, but some is cast about loose, and much is crushed; in fact, unless it crosses the whole way, it acts chiefly as a beacon to warn carriages, as long as possible, from those parts.

The material is, however, chiefly laid down in winter, and is gradually consolidated by the traffic, commencing in the ordinary manner along the edges; but by such means, and surrounded by mud, there is a very great loss before the portion that ultimately remains becomes fixed.

It can hardly be doubted but that means might be devised for greatly improving on this system, and obtaining better roadways, even at the same expense.

It would not be easy to define at once, in every particular, exactly how it is to be done; but it might be worthy of experiment.

The two principal measures to be adopted or ameliorated are—

1st, To keep the roadways always clear of any collection of dirt upon them.

2ndly, To fix on the means for laying down, in the most advantageous manner, the broken stone that will be necessary to maintain adequate thickness for bearing the traffic.

First, With regard to the cleaning, it will be done chiefly (it may be hoped *entirely*) with the broom.* It will perhaps be difficult to be executed amidst all the traffic, but not so much so as would appear, judging from the present state of the roads; because it is contemplated that at no time will there be more than a very slight quantity of dirt to remove, and that chiefly of the matter dropped upon the surface.

It is impossible exactly to foresee how often each part will require to be swept over; the most frequented thoroughfares perhaps daily, others from that to once a week, or even ten days, the least being on those that are paved and least traversed.

It is to be understood that this operation will take place in summer as well as winter, in the driest as well as in the wettest weather, though perhaps not so often.

How the sweepings are to be put together and carried off will be another arrangement for experiment; the point will be not to waste horse-hire by keeping the carts lingering all day over perhaps two or three miles, yet at the same time so to dispose of the mass collected in the street as not to be in the way of the traffic or scattered about until the cart shall come round for it.

It is suggested that any medium course of partial clearance—that is, making the streets *somewhat* more clean than at present, would certainly lead to failure; it would cause an increase of expense in one item, without a compensating reduction in others: it must be the endeavour to keep *perfectly clean*, and free at all times from mud or dust, whatever parts may be submitted to the operation, so that every wheel may roll over the hard compact surface of stone alone.

This can only be partially effected on the present road surface, the whole mass is

* This is done now in many parts of London.—Ed.

so deeply mixed up with dirt, but may be done perfectly after every successive general spreading of broken stone hereafter.

If these streets were constantly kept perfectly clean, hard, and even, and the material was of a tough good quality, the actual wear of the surface would be extremely small, less, no doubt, than *an inch* in the year, even in those most frequented; the wheels, in fact, would be running over a smooth pavement made of small materials.*

Still, even at that rate, it would be more convenient, where the intercourse is nearly incessant, to have the supplies laid down occasionally in general masses; in preference to the course recommended for roads under other circumstances, by minute repairs *exclusively;* because in this case the small additions would be too frequent and general, and more especially because in towns the more extensive spreading of broken stone can without difficulty be greatly consolidated at once by rolling.

It is suggested that the thickness of consolidated metalling need never exceed about nine inches, nor ever be less than four or five; when reduced to that minimum the surface should be loosely picked, and about four or five inches of broken stone laid along the street, and most completely rolled, with the necessary blinding on the most approved system.

It is indispensable that it should be made thoroughly firm; it would then bring the outer crust from four or five inches to eight or nine, according to the importance of the street.

The new-laid material must be well attended to, and rolled until it is perceived that it is perfect in form, and so solid that neither wheels nor horses' feet make injurious impression on it.

This will be the substance for regular wear, and it is calculated will last two, three, or more years; small depressions, inequalities, or want of form, as soon as they can be perceived, being minutely corrected from time to time, by picking the surface, and then patching with small quantities of stone, broken fine.

There are 76 statute miles of streets under the Dublin Paving Board, of which 52 of the most important are macadamized, and 24, chiefly inferior thoroughfares, paved.

The expense of their maintenance in the year 1842, exclusive of sewers and footway, flagging, &c., was—

	£
For Macadamization and paving	11,036
,, Scavengering	7,394
,, Watering	1,842
	20,272

From the first item about £4450 may be deducted as the expenses of the paved streets, of crossings, gravel, &c., leaving £6586 for the macadamization.

Thus we have £15,822 for the cost of maintenance of the streets, exclusive of paving, crossings, &c., which may be supposed to remain as at present.

With regard to the relative expense of the system now proposed, as compared with the above, we shall have the following items of increase:—

1. The street labour, in sweeping, keeping them clear of loose stones, and of all deposit or extraneous matter, patching the little inequalities that may occur, and general attention.

* The wear of surface on a road of great traffic, kept very firm, even, and clean, in France, was found to be less than half an inch in the year.

2. Rolling thoroughly at the times of the general laying down of material.

(1.) The first will require a very large expenditure to give it full effect.

The great leading streets may require an average of one man for every 200 yards, —less in summer and more in winter; others will not require so many, gradually reducing down to the smaller paved streets, for which one man per half-mile, or, perhaps, even per mile, may be ample.

Suppose, then, an average throughout the year of about four per mile; 300 men daily would be employed in this service, which, at 1*s.* 4*d.* each, would amount to £6260 per annum.

Then, suppose 20 one-horse carts daily, for the removal of the sweepings, at 4*s.* 6*d.* the cart, would amount to £1048 10*s.*, making £7668 10*s.* for this most material item.

(2.) For the rolling, estimating the *general* laying down of broken stone over every part of the macadamized ways to take place once in two or three years, we will allow 20 miles to be rolled per annum: the average width of the streets is 32 feet, and the cost consequently may be £38 per mile, or £760 for the 20 miles.

	£	s.	d.
Add this	760	0	0
To the above estimate	7,668	10	0
The amount will be	8,428	10	0
Which deducted from	15,822	0	0
Leaves for broken stone and watering . .	7,393	10	0

The latter will be greatly reduced; but leaving it as before, as an extraneous charge, namely, £1842, there will remain £5551 10*s.* for broken stone.

The cost for this item is now about £5700, but it is one in which there must be a very considerable reduction, at least equal to one-half, when the system is thoroughly acted upon; say that the cost should then amount to £3000, there will remain £2500 for contingencies, or to make good any deficiencies in the above calculations, which, however, it is believed are by no means forced.

There will be an item of increase in the available funds, though not large, in the sale of the street sweepings, which will be all valuable manure, and a saving in the necessity for carrying any to spoil.

Where road-work is to be done as proposed, chiefly by daily labourers, it is a matter of consequence so to adjust the work as to require a constant and uniform supply: this is done now in Dublin very much by working at the paved streets, when less is required on those that are macadamized, and such arrangement may be continued.

ON ROLLING NEW-MADE ROADS.

The importance of rolling roads, either newly constructed, or when subjected to extensive repairs, seems never to have been duly appreciated.

Lines of any length of new-laid broken stone may be deemed nearly impracticable to ordinary traffic; the worst and most hilly old roads are always taken in preference to the new roads while in that state, although the latter may be much shorter, and with very improved levels.

At length the old road is shut up, carriages are forced to take the new, occasioning the greatest inconvenience and drawback to the intercourse for perhaps a year or more, a great wear and waste of the material, and a considerable expenditure in

watching and maintenance, until the material, or what remains of it, shall be finally consolidated, and even then in a very imperfect form, unless great pains are taken with it.

The rolling is, in fact, effected, but in the most distressing and expensive manner, and by carriages and horses very ill adapted to it.

These evils may be entirely prevented, the road put at once into good working condition, and, certainly, a considerable expense eventually saved, by thorough systematic rolling; nor ought any road to be considered as *made* until that operation shall be completely effected.

Three reasons have probably operated to prevent this principle having been acknowledged and acted upon.

1. Because the traffic on the road will, sooner or later, do the work, thereby apparently reducing, in a small degree, the cost of the original construction or repair.

2. Because a roller is not usually at hand, and from its weight and unmanageable character, it is most inconvenient and expensive to be removed from one place to another, so that in most cases one would have to be constructed for the purpose, and subsequently be useless.

3. Much uncertainty, as yet, as to the best manner of operating, its efficacy, and expense.

The first reason is founded completely on error; it is manifest that this manner of completing the road by the traffic is most inconvenient, and occasions enormous sacrifices by the parties using the road, and consequently a great loss to the public in general; nor can there be a doubt that the *actual expenditure on the subsequent early maintenance of the road itself is greater than would be incurred by at once operating thoroughly with the roller.*

With regard to the second reason, there are many ways in which the objection can be greatly alleviated.

Although there is some justice in the third, and that the most perfect mode of proceeding is not yet perhaps understood, there is so much useful effect to be produced by any, that it is surprising that it has not been reduced to just principles by experiment, and generally adopted.

The practice of rolling has been rare, and almost entirely confined to gentlemen's demesnes, and occasionally to the macadamized roadways in some cities; but in the latter, it is believed, without the application of sufficient means for the purpose.

There are certain considerations which may serve as guides to arrive at just conclusions with regard to this proceeding.

1. A roller should not be too heavy in proportion to its bearing surface, or, instead of binding the material in the position and form laid down and desired, it will press it more or less into the substratum; much of the material will thus become useless, and it will be very troublesome to obtain the necessary resistance for the consolidation.

2. It must not be too light, or the effect will be too small ever to gain the object fully; or at any rate, without an extent of operation that would be very costly or inconvenient.

It is believed that the ordinary rollers are too light, which may have thrown the practice into disrepute.

For the Dublin streets they have a roller of two contiguous cylinders, each of 4 feet diameter and 1 foot 6 inches in width, making in all a bearing of 3 feet; it weighs 2 tons 3 cwt.; only two horses are attached to it, but the work is exceedingly heavy. It is applied to successive layers of material, in new formations, and about an inch of gravel is worked into the upper layer or surface. It is said to

consolidate the roadway very effectually, but might probably be improved by adding to its weight.*

From other recorded trials, however, there is reason to believe that a road roller should not be lighter than 28 cwt. for every 12 inches lineal of bearing on the road; that is, if four feet wide, that it should weigh 5 tons 12 cwt.; if three feet, 4 tons 4 cwt., &c.; and that it should only be applied to the upper surface of all.

A roller somewhat heavier than 28 cwt. per foot would be more effective, but it is better after that limit to gain the object rather by adding to the number of times passing over the surface than incur the inconveniences of the heavier machinery.

This is one very interesting point to prove, namely, the relative effects of light and heavy rollers, taking into account the number of turns required by each.

3. For effect, the wider a roller can be, the better, because the operation will be more quickly performed, and because, in proportion as it is narrow, will there be a tendency to force the broken stone laterally from under its action; but, as the weight must be in proportion to its bearing surface, the width must be limited to a degree that will prevent that weight being too unwieldy; a very narrow roller might also have a tendency to overturn. On the other hand, one that is very wide may take up too much room, if the road is open to traffic during the time of its use.

4. Horses should not be obliged to use very great exertions in drawing a roller, or the action of their feet will discompose the loose stones very inconveniently; therefore, as the draught is very heavy at first, and never very light up to the last of the operation, they should not have more than from 10 to 12 cwt. each to draw at first, nor so much as a ton each at last.

5. It would be desirable not to put more than four horses to such a machine, because as the number of horses is multiplied, it becomes more difficult to obtain a perfectly united effort from them; but on the above data a roller of 4 tons maximum weight might be too small for the best service, and as six horses may perhaps be applied without *much* inconvenience, it is proposed to give that number as a limit, and to allow 5 tons 12 cwt. as the maximum weight for the roller; this, at 28 cwt. per foot of bearing, would give it a width of 4 feet.

From the Continent we have records of several trials that have been made of late years of the effect of rolling new-laid material on roads; although there are discrepancies in some of the particulars, there are many in which all agree; and in all the practice has been strongly recommended.

The one that seems to be the most practical is a roller described as first used in the Prussian provinces on the Rhine, and from thence introduced with some modification into a neighbouring district in France.

It consists of a cylinder of cast iron of about 4 feet 3½ inches wide and 4 feet 3½ inches diameter.† On the axle, by means of iron stanchions, is fixed a large wood case of 6 feet 4½ inches long, 5 feet 8½ inches wide, and 1 foot 8 inches high, open at top.

This roller has a pole before and behind, in order to be able to draw it in either direction without turning; the hind pole is sometimes used to assist in guiding it. It has also a drag, by the pressure of a board on its face, in the manner used for French waggons.

The cylinder and other iron-work weighs nearly 2 tons; the case and wood-work about 19 cwt., making the whole 2 tons 19 cwt.

* A short street (Herbert Street), made in 1836, and then well rolled, had never required repair or new material up to the time of writing these notes (1843); it is a good street, but not a great thoroughfare.

† These and other dimensions are necessarily in odd numbers, owing to reducing them from French measures and weights.

The case will contain a weight of stone of 2 tons 19 cwt. when completely loaded; therefore the entire weight can be brought up to 5 tons 18 cwt.

Six *strong* horses worked it well.

It is passed over the entire surface of the road once or twice without any loading, and weighing consequently nearly 3 tons, to obtain a first settlement of the loose material; then one or two turns with about 1½ ton loading, making 4½ tons; and then the last turns, making ten in all, with the full loading, when it becomes 5 tons 18 cwt.

Traversing 12 miles, it will thus completely roll about 3000 square yards* in one day, or about a quarter of a mile of road of 21 feet width.

All accounts agree as to the absolute necessity of applying some gravel or other sharp, gritty, very fine stuff on the surface, during the operation, without which it will not be thoroughly bound.

The consolidation commences with the lower part, which is the first to get fixed and arranged; and when, after about six turns over the whole, the upper layers have become tolerably firm and well bedded, some sand, or stone-dust, or, what is best of all, sharp gravel, is very lightly sprinkled over it by degrees at every successive rolling, *solely for the purpose of filling up the interstices* of the broken stone, and *not to cover it;* about 3 cubic yards in the whole per 100 square yards (equal to about an inch in thickness if spread over the whole surface) will be required. It is essential that this small stuff be not applied earlier, or it will get to the lower strata, and not only be wasted, but prove injurious. The object is that it should penetrate for two or three inches only, to help to bind the *surface.*

Provided the upper interstices are filled, the less gravel used the better; therefore it is applied by little and little after each of the three or four last successive passages of the roller, and then only over the places where there are open joints.

After the work, if well done, is completed, it is stated that such is the effect that the upper crust may be raised in cakes of six or seven square feet at a time, which it could never be without the gravel.

The effect may be improved also by having the upper inch or two of stone finer than the rest, say, to pass a ring of 1¼ inch or 1½ inch.

This work should be done in *wet* weather, or the material will require to be profusely watered artificially.

It will be better that it should not absolutely rain, unless *very lightly, when the gravel is applied* (although the stoning should be wet), as it will cause it to adhere to the roller, and even at times to bring up the broken stone with it. In frost it is of no use attempting to roll. The state of the material, as regards its being wet or dry, will have great influence in the success of the operation.

The form of the road will be best preserved by rolling from the two sides towards the middle, and not commencing along the latter.

The calculated expense of the work in France was—

	£	s.	d.
For six horses and two drivers, per day	1	4	0
For six labourers attending on the road, assisting at the roller, levelling inequalities, spreading gravel, &c. . .	0	7	0
Total for 3000 square yards . .	1	11	0

* Some of the calculations are not *strictly* in accordance with the data, because the data themselves are not given in minute fractional parts, and consequently the reduction of the results will show a difference; but it is very small, and of no consequence in a general consideration of the matter.

being about one penny for eight square yards, or one penny per running yard of road, twenty-four feet wide, and amounting to about £7 5s. per mile.

For Ireland these prices would have to be increased, thus—

	£	s.	d.
For six horses, with drivers, per day	1	7	0
For six labourers, at 1s. 4d.	0	8	0
	1	15	0

It is considered that a modification would be desirable in this foreign roller, by making it only four feet wide; its weight might then be, with its box for the additional loading, &c., about $2\frac{1}{2}$ tons, which with an extra loading of 2 tons 2 cwt. would bring it to the 5 tons 12 cwt. for its extreme weight, at 28 cwt. per foot.

Such a roller passing ten times over every part, and working twelve miles per day, would require five days, and the operation cost about £8 15s. per mile of road, of twenty-four feet wide completed.

The gravel ought to be considered as material, but in this case it is an addition to what would otherwise be applied; the cost therefore must be added.

Suppose it to amount to one shilling per cube yard, the expense, at thirty-six square yards per cube yard of gravel, will be about £19 5s. per mile of road of twenty-four feet wide.

This would bring the whole to an amount of £28 per mile.

However perfect the rolling may be, there will be at the end a slight elasticity and yielding of the surface, which will only become quite firm and hard after some days' traffic, say from six to ten when tolerably frequented, during which its form and smoothness must be carefully attended to; add, therefore, £2 per mile for that extra work, and the cost will be £30 per mile.

The expense of the operation of the roller (independent of the gravel) is so small, that if the weight is under-estimated, so that the width of the roller should require to be reduced to three feet, thus adding one-fourth to that part of the outlay, or that it would require to be passed a greater number of times more than calculated, that increase would not be of essential importance on the gross amount.

If artificial watering should be necessary, that expense also must be added, but it would be small.

The subsequent wear of material, under proper care, will be most trifling. One French Engineer states, that where the rolling in this manner has been successfully performed, there has never been a necessity for applying above one cubic yard of broken stone per 300 square yards of road in the next year; that in one instance only one cubic yard per 1500 square yards was used, although on a road subject to the passage of 400 horses in draught per day; and on another road no fresh stone was laid for three years.

To make a more direct comparison, however, of expense, it may be assumed that a much greater diminution of thickness will take place in the consolidation by the traffic than if effected at once by the rolling, because the narrow wheels of ordinary carriages penetrate into the loose matter, and force the lower part of it partially into the subsoil. The displacement, and grinding, and crushing is also very great; whereas, in rolling, the entire is preserved and in its proper place: it may therefore not be too much to estimate, that if it require ten inches of loose material to bind into six inches by the ordinary process, as it probably would, eight inches, well rolled, would give the same; if so, the saving at once would be very great: thus, suppose the covering of one inch of stone to cost as much as two inches of gravel, that is, if the gravel is valued as above, at 1s. per cubic yard, that the stone be valued at 2s.;

then we have four times the cost of the gravel, which was stated to be £20 per mile, or £80 to set against the £30, estimated expense of rolling.

If the rolling effected a saving of only one inch of the broken stone, still the cost of that one inch would exceed that of the rolling, including the gravel.

This last calculation is given only as a proof of the saving, and not as recommending the reduction of the mass of material laid down to a minimum; on the contrary, as the rolling of the surface is a final measure, and requires no renewal until the road is worn to a minimum thickness, the most economical plan probably would be to apply a considerable degree of substance at once, enough to last some years, so as to reduce the number of periods when rolling would be necessary.

In some few situations the very formation of the road may be made subservient to its rolling.

In the construction of a new road over the Carey Mountain, in the county of Antrim, material for stoning the road was quarried in several parts of the mountain up to its summit.

Some carts were made with wheels of four-inch tires, and the laying of the broken stone being commenced close to the quarry, the work was carried on from each quarry *down hill*, the loaded carts being taken over the new-laid material, working systematically over the entire width of the road, and discharged, below, returning up the hill light. By the time the work was completed, the road had acquired in this way a considerable degree of consolidation without extra labour.

A roller of the weight of five or six tons may be worked up inclines of one in twenty by increasing the number of horses, but not steeper; if at all exceeding one in thirty, it would probably be better to apply the roller in its lightest state, and increase the number of passages.

It is very desirable to complete rapidly what is once begun, but it is attended with the disadvantage of taking up short lengths at a time, which leads to the occasion for turning the roller very frequently, a manœuvre that is particularly inconvenient.

Although certain dimensions and weights are suggested to be likely to prove the most efficient, any other kinds that happen to be in possession might be tried and adapted to the above principles, which will usually require weight to be added with the successive rollings: this may be done in various ways according to circumstances and situations; the most simple will be a large case on the roller, for loading with stone.

In or near towns, iron weights might be used instead of stone, partly on or suspended to the axle, within the cylinder, or in a case outside, which might be then much smaller, and the weight be more compact and more easily shifted; or for use IN a town, when the most efficient dimensions and weights were ascertained, rollers might be prepared of two or three qualities, that is, all of the same extent of bearing, but of cylinders of different weights, from the lightest to the heaviest, and brought in succession on to the work.

Note.—This whole question is pre-eminently one which requires the supervision of government officers, both as to the construction and repairs of all roads in the vicinity of large towns, as well as all main thoroughfares in any positions, in order that some efficient system may be uniformly carried out, instead of so important a public matter being left to the control of local boards and vestries.—Ed.

ROCKET ARTILLERY.*—Congreve rockets are now supplied to all troops of horse artillery and some field batteries, but great difference of opinion exists as to

* Chiefly from the 'Royal Artillery Handbook for Field Service.' See also 'Pyrotechny,' 184.

their value for warlike purposes. They possess the advantage, however, of serving either as shot, shell, or carcase, and their moral effect, especially against cavalry, is very great. Their portability is very valuable in a hilly country, and they require but few men to work them; but their irregularity of flight is undoubtedly a great defect, much increased by a side wind, to allow for which a rocket must be laid to leeward of the object, as the pressure will be chiefly exerted on the stick.

The motion of the rocket is caused by the gas generated in the interior, when the rocket is fired, pressing with greater force on the head than on the base, in consequence of a large portion escaping through the holes or vents in the latter; the action being similar to the recoil of a gun fired with powder alone.

A stick or long rod is screwed into the centre hole in the base, in order to counteract the tendency to rotation, and to retain the rocket in its initial direction.

Rockets are fired from iron tubes raised above the ground, and made capable of elevation. They may also be laid on the ground and fired in volleys, the head being slightly elevated.

For field service, the rockets are conveyed in carriages consisting of body and limber, the cases and sticks being in separate boxes. On coming into action the tubes are set up and properly directed and elevated; the rocket is inserted about half way, and the priming loosened; it is then pushed beyond the spring-catch and gently drawn back till stopped by the spring. The 12-pounder shell rocket should not be fired at less than 12°, nor the 24-pounder at less than 20° elevation.

The two brass scales formerly used for adjusting the boring bits have been superseded by a four-sided wooden scale, having on the successive sides the scales for the 24-pounder, 12-pounder, 6-pounder, and 3-pounder, as shown in page 379. The method of using it may be shown as follows. Suppose it is required to burst a 24-pounder at a range of 1500 yards, the whole of the fuze, composition, and about half of the solid of the rocket must be bored; place, therefore, the point of the boring bit against the shoulder A of the scale marked 24-pounder, slide the edge of the stopper to a point half-way between B and C and screw it fast, then bore into the rocket till the stopper meets the apex of the shell.

TABLE OF RANGES FROM AN AVERAGE RESULT OF ROCKET PRACTICE, 1852.

Elevation.	3 Pounder.	6-Pounder.	12-Pounder.	24-Pounder.
	YARDS.	YARDS.	YARDS.	YARDS.
8°	500			
9	650			
10	800	600		
11	900	750		
12	1000	900	700	
13	1100	1000	850	
14	1200	1100	1000	
15	1300	1200	1100	
17	1500	1400	1300	
20	1700	1700	1700	1300
22	...	1800	...	1500
24	...	1900	...	1700
25	1900	2000	2100	1800
27	...	...	...	2000
30	...	...	2500	2300
35	...	...	...	2800
37	...	2500	...	3000
40	...	...	3200	3200
47	...	...	...	3400

When the wind is in front, add half a degree to the above elevations; when in rear deduct the same amount.

RANGES AT WHICH SHELL ROCKETS MAY BE EXPECTED TO BURST.

	3-Pounder.	6-Pounder.	12-Pounder.	24-Pounder.
	YARDS.	YARDS.	YARDS.	YARDS.
Whole length of fuze	1800	2400	3100	3300
Fuze bored out	750	1000	1600	2000
Solid bored to within 1·5 inch of top of hollow in 24-pounder, and 1 inch in the other natures	400	450		

Hale's rocket has not a stick, but the base, which is in form a frustum of a cone, has a large vent hole through the axis, and 5 small holes, called "tangential holes," cut through its surface into the rocket in an oblique direction. The object of these holes is to give the rocket, by the escape of the gas through them, a rotary motion round the larger axis, causing it to proceed point foremost like a rifled projectile; but it is considered that the rocket will soon lose this motion by the consumption of the composition, and will strike the object in an uncertain position, and without the issue of flame, which is so important.

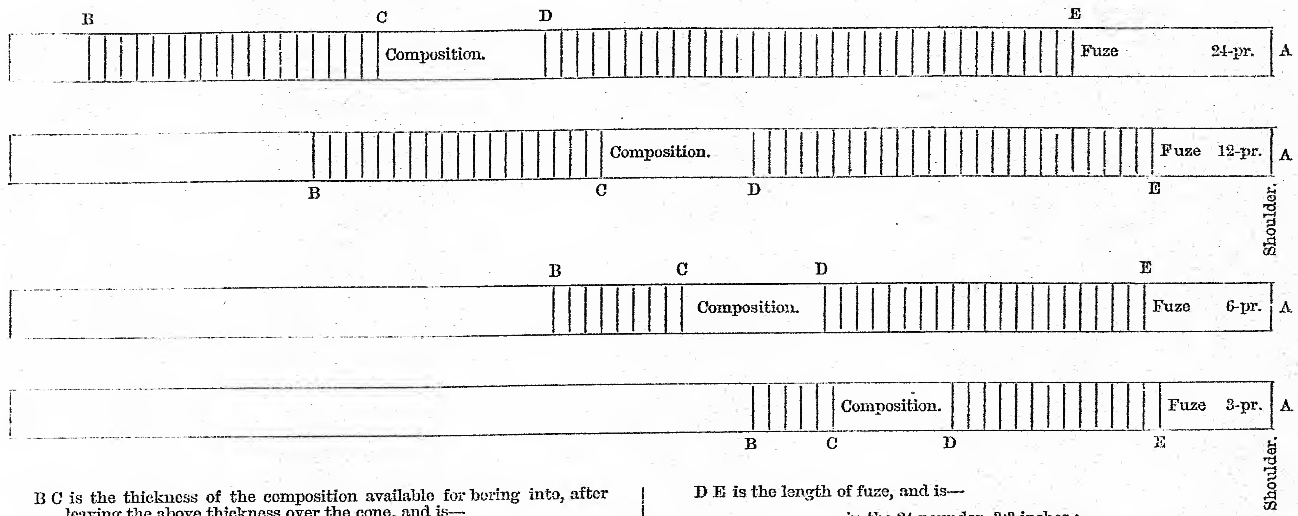
C. R. B.

A B denotes the greatest length to which the rocket composition can be bored, so as to leave 1·5 inch over the end of the cone in the 24-pounders, and 1 inch in the other natures.

A B is in the 24 pounder, 7·8 inches;
in the 12-pounder, 6·2 inches;
in the 6-pounder, 4·7 inches; and
in the 3-pounder, 3 inches.

A D is the distance from the surface of the shell to the inner extremity of the fuze, and is—

in the 24-pounder, 4·9 inches;
in the 12-pounder, 3·5 inches;
in the 6-pounder, 2·9 inches; and
in the 3-pounder, 2 inches.



B C is the thickness of the composition available for boring into, after leaving the above thickness over the cone, and is—

in the 24-pounder, 1·8 inch;
in the 12-pounder, 1·8 inch;
in the 6-pounder, ·8 inch; and
in the 3-pounder, ·5 inch.

D E is the length of fuze, and is—

in the 24-pounder, 3·3 inches;
in the 12-pounder, 2·5 inches;
in the 6-pounder, 2 inches; and
in the 3-pounder, 1·3 inch.

S.

SANITARY PRECAUTIONS.*

In a publication like the present, it has not been considered necessary to insert a very full and elaborate article on a subject of so general and extended a nature as that under consideration; while on the other hand, a work on Military Sciences would be greatly wanting in completeness, were no notice taken of such sanitary questions as concern the health and well-being of the soldier. The writer of this paper has therefore confined himself to that portion of the subject, and has founded his remarks chiefly on the recommendations of the commissioners appointed to inquire into the sanitary condition of the army, in 1857, who numbered among themselves, or received the testimony of, the leading men of all professions connected with the working out of this important subject.

On comparing the various statistical returns, the commissioners found that the mortality among the troops, during peace, was considerably greater than the average among the civil population at the same ages; although the soldier is a picked life, both at first entry and by continual weeding through invaliding, pensioning, &c., while the civil population is burdened with those primarily unhealthy, and with discharged invalided soldiers, besides vagrants and all kinds of dregs of population unfit for any useful employment.

The causes assigned for the high rates of mortality in the army are such as of themselves to be prejudicial in all states of society, viz. :—

1. Exposure at night.
2. Intemperance and debauchery.
3. Want of exercise and employment.
4. Crowding, bad ventilation, and defective sewerage, &c.

And the question, of course, arises whether these are greater than in the civil population.

1st. The night exposure is not excessive, nor at all approaching that of the police force; but the injury is probably much increased by the guard-rooms being generally very warm, and the men lying down in their great coats, and then going out in a state of profuse perspiration to stay two hours in the night air, and returning often with their coats thoroughly wetted with rain to again lie down for a few hours.

2nd. Intemperance and debauchery. There does not appear any reason to suppose that the soldier is more intemperate than the general class from which he is taken, nor are diseases of the digestive organs, which are said to be those usually resulting from intemperance, as prevalent as those of a pulmonary character. Debauchery undoubtedly is more prevalent where large numbers of comparatively young men are massed together in towns, as soldiers are. This leads to serious disease, greatly increased by the soldier concealing it, and it ultimately affects the constitution, but is not by any means sufficient to account for the great mortality.

3rd. Want of exercise and employment. This appears to be one very prolific source of disease in the army. With the exception of the small amount of labour expended in cleaning his accoutrements, the infantry soldier's regular exercise is of the most monotonous character, and performed in constrained and uncomfortable attitudes. The greatly diminished rate of mortality in the cavalry, 13·6 to 17·9, may be con-

* By Capt. Binney, R.E.

sidered as being mainly attributable to the greater amount and variety of the trooper's exercise, partly on horseback and partly on foot; while the muscular exertion required in grooming his horse is far greater than anything demanded of the infantry soldier.

Colonel Lindsay, of the Guards, in speaking of the soldier's life, says: "Perhaps no living individual suffers more than he from ennui. He has no employment save his drill and his duties: these are of the most monotonous and uninteresting description, so much so that you cannot increase their amount without wearying and disgusting him. All he has to do is under restraint; he is not like a working man or an artisan; a working man digs and his mind is his own, an artisan is interested in the work in which he is engaged; but a soldier has to give you all his attention, and he has nothing to show for the work done."

There is probably nothing that so sustains a man under labour of various kinds, as the thought that there will be a certain portion of work completed; or, at least, "something to show," as Colonel Lindsay says, for the time expended.

It would seem, then, that it would be well in every way to encourage soldiers to practise athletic exercises and out-door games as much as possible. It also is a question worthy of great consideration, whether they might not be largely employed in connection with Government works at a small rate of working pay, and even allowed to assist civilians when requisite. A large comfortable well-lighted reading-room should also be provided, with a number of useful, and at the same time entertaining, books, for the evening occupation, coffee being kept ready for those who might require it.

There still remained, however, the fact that there was throughout the army a large proportion of disease of the chest of a chronic character, viz, 12·5 per 1000 in the Guards, and 8·9 in the Line, to 5·8 in the civil population, which cannot be attributed to any of the foregoing causes. It is necessary, then, to examine whether the fourth cause produces such an undue mortality in the army, viz.—

4th. Crowding, bad ventilation, and defective sewerage, &c.

Before considering the magnitude of this evil, it may be well to notice that the native regiments in India are the only ones in which the mortality does not exceed that of the population from which they are drawn; and the Sepoys are the only soldiers not in barracks, each man receiving a small sum as hutting money, with which he buys a few mats and erects a hut for himself, frequently sleeping outside even of this. It may also be noted that the mortality of the army before Sebastopol, when hutted in 1856, was very low. During twenty-two weeks, ending 31st May, 1856, including deaths by violence and accident, the mortality of that army was only at the rate per annum of 12·5 per 1000, against 17·9 in the Line, and 20·4 in the Guards in England.

Of the deaths in the Line 57·277 per cent. are caused by diseases of the respiratory organs, and in the Guards 67·683 per cent.

On the question of overcrowding, it may be observed that the minimum cubic space allowed by regulation—450 feet per man—was far below that which is necessary for health, and that, even of this small modicum, there is, in the older barracks, frequently a deficiency practically of a third and sometimes one-half; besides which the beds are often placed so close that even the regulated space of one foot between them is not adhered to; and it is clearly proved that the distance between the beds is of still more consequence than the mere cubic space arising from a lofty room. The window ventilation is generally insufficient, and the soldiers always, if possible, stop up every ventilator to make the rooms warmer. The result is that—especially when the barrack-room is partly below the ground—the soldier sleeps in a fœtid atmosphere, and lays thus too often the seeds of pulmonary disease.

The testimony of the non-commissioned officers is to the effect that the men feel uncomfortable in the morning, while to themselves, going in from the open air, the scent was so intolerable as to render it necessary to call to the orderly to open the window at once. The writer can speak from experience to the same effect, he having frequently been obliged to stop to have the windows opened before he could enter a barrack-room for the purpose of making an inspection.

The question then arises,—what can be done to lessen this enormous mortality?—an evil productive of great expense to the country, even apart from the higher motive of saving life.

The first cause of disease does not admit of any remedy beyond that of providing a more effective kind of clothing for the men on sentry during a wet night, and making it imperative on the officer or non-commissioned officer, in charge of the guard, to see that this outer coat is removed on returning to the guard-room, before lying down.

The second cause may be greatly lessened by providing efficient remedies for the third; and specially, by taking every opportunity of endeavouring to lead the soldier's mind to higher and holier aspirations, by presenting to him, in all its fulness, the Gospel of the Grace of the Lord Jesus Christ; *not through compulsory* attendances at church or chapel, but by the earnest heartfelt converse of men, of whatever rank, who know and can testify, from their own experience, the satisfying nature of the love of God implanted in the heart of a pardoned sinner.

For the third remedy, it has been often suggested that every sort of encouragement should be given to the men, to strengthen their powers, both bodily and mental, by athletic exercises and such out-door games as tend to develop the muscles and produce activity and endurance. It may be looked upon as a matter of consideration whether the men might not be advantageously employed in Government works, and especially on the necessary repairs of barracks, barrack furniture, &c., at a small daily rate of pay.

A room for reading and in-door games has also been strongly recommended, with a refreshment-room attached where the men might be provided with tea, coffee, and tobacco.

With reference to the fourth evil of overcrowding, &c., some of the remedies are very simple, for it is easy to arrange that the rooms shall be inhabited by a less number of men, or in new barracks to see that the rooms shall be built *for* and allotted *to* such a number that the cubical space for each man may be not less than 600 feet, and that the beds may be placed at least 3 feet apart from edge to edge, and with not less than 10 feet between the ends of the beds when turned down at night.

The urine tubs should on no account be used, but either earthenware utensils substituted, or slate urinals constructed outside the sleeping-rooms, with running water through them, as has been done at the Duke of York's school.

In all barracks where they do not exist, ablution-rooms and baths, laundry and drying-rooms should be constructed, and provided with an abundant supply of pure water. Also proper quarters for the non-commissioned officers and married soldiers should be built in all cases.

All rooms for the use of the men should be well warmed and lighted, gas being used wherever practicable. Means should be provided by the erection of Grant's, or any other approved apparatus, for enabling the men to bake, fry, &c., so as to ensure a variety in the cooking, and, if practicable, a variety in the food itself should be adopted, and a sufficient quantity given to supply the proper amount of nutriment, the whole being provided by the Commissariat to ensure good quality. All open privies with cesspools should be abolished, as injurious alike to health and

decency; and seated closets, wholly or partially closed and screened, should be substituted, with either a continuous flow of water or the means of flushing the channel several times a day to carry the soil into a suitable sewer. All sinks should be double-trapped.

Where practicable, the barrack-rooms should have windows on both sides to ensure proper ventilation, and openings should be made both near the floor and close under the ceiling for the same purpose. Where the buildings do not admit of this, it may often be feasible to introduce a hollow girder, open at both ends to the external air, but closed at the centre, at each side of which, on the underside of the girder, openings may be made to allow of the ingress of the fresh, and egress of the foul air, according to the side from which the wind blows. Any of these openings, however, will require gratings over them, or some means adopted to prevent the soldiers—who, like most of their class, are ignorant of the advantages of pure air and water—from stopping up the aperture.

In every case, before new barracks are built, the various procurable sites should be carefully inspected by some one well versed in sanitary questions, who should also be consulted as to the arrangement of the plan.

In taking the field, it would be well that a competent sanitary officer should always be attached to the Quartermaster-General's Staff, who should be especially charged with the selection of sites for encamping, and the arrangements of drainage, &c., and whose opinion the commanding officer should be required to follow, or assign a reason for doing otherwise.

The character of the dress, and its suitability for the particular climate in which the soldier may be employed, should be specially attended to, so as to ensure freedom to the limbs, and the absence of pressure on the head and feet, with proper protection from the action of the weather.

HOSPITALS.

Having considered one point very important in connection with the health and mortality of the soldier, viz., that all means should be adopted, as already suggested, by improving the food, accommodation, &c., to prevent his becoming ill, it is necessary to refer now to the means to be adopted to obviate an undue amount of fatal result among the cases admitted to hospital.

The site of a hospital should always be dry, and, if possible, gravelly, with ample space around it, and with easy communication between it and the different points from which it is to be supplied. It should also be capable of being easily drained, and the most perfect kind of sewerage should be adopted, and kept as much as possible clear of the building. Water-closets should in every case be constructed in lieu of privies, and, with the urinals, sinks, &c., cut off from the hospital by a well ventilated lobby.

The *minimum* space allotted to each bed should be 1200 feet at home, and 1500 in tropical climates, with a *minimum* distance of 4 feet between the sides, and 12 feet between the ends of the bedsteads.

An ample supply of natural light and ventilation should be secured by making the building in separate pavilions with windows on opposite sides, and sufficient provision for warming and lighting, according to the season and weather, should be made on the requisition of the medical officer, without further authority.

It is important that the walls and ceilings be made of some non-porous material, such as Dutch tiles, Parian cement, &c., instead of brick and plaster, which absorb at one time and give out at another the noxious gases formed in the room, and are not capable of being washed. The staircases and landings should be of stone.

Lavatories, baths, and laundries, with all the best arrangements, should be constructed in connection with the establishment, and ranges erected in the kitchens to admit of roasting and stewing as well as boiling, for variety.

In the field, hospital marquees should accompany each division, and should be supplied with a complete equipment of all the necessary stores, for the conveyance of which a certain amount of horse and wheel transport should be permanently provided. A regular arrangement should be made for the home transport of those who seem equal to the voyage and are not likely soon to recover.

As far as the army is concerned, many of these recommendations have been carried out with marked benefit, the deaths per 1000 having been reduced to the same proportion as in the ordinary population; and the true figure for picked lives in a favourable position, viz., 7 per 1000, seems, according to Dr. Farr's report for 1860, to have been attained.

SAP.—The whole subject of Sapping, or making way towards an enemy under cover from his fire, has assumed a perfectly new aspect since the introduction of the present long range and rifled arms, and is now under investigation. It appears, however, necessary, till some better way is ascertained and fully adopted, to insert a description of the present mode of carrying on the work. The saps are of various kinds, viz., *Single*, *Flying*, and *Double*.

Single Sap.

This is of two kinds—kneeling and standing. The kneeling sap is constructed in the following manner, and requires the undermentioned men and materials, viz.:—1 N. C. Officer and 4 Sappers, 4 pickaxes, 4 shovels, 1 sap roller, 1 sap fork (long-handled), 2 ditto (short-handled), 1 measuring rod (6 feet), 2 gauges (18 inches), 1 ditto (20 inches), 1 mallet, a few short pickets, and a supply of gabions, sap faggots, and 6-foot fascines.

The men are numbered from 1 to 4—Nos. 1 and 2 working on their knees, and 3 and 4 standing.

No. 1 excavates a trench 18 inches wide and deep, leaving a berm 18 inches wide between it and the gabion, which he arranges with a small sap fork in contact with the sap roller or mantlet placed at the head of the sap for protection. At the junction of every pair of gabions, and of the first gabion and sap roller, he places a sap faggot or two sandbags on end, one above the other. He must always work in rear of a filled gabion, and never place an empty one till he has loosened sufficient earth to fill it, which he should do by dropping the earth carefully in, not throwing it over, occasionally striking the side of the gabion to shake down the earth. After he has filled two gabions, and prepared earth for a third, and placed it in position, he goes to the rear, and replaces No. 4, who becomes 3, while 3 becomes 2, and 2 becomes 1.

No. 2 widens the trench of No. 1, 20 inches. He helps No. 1 to push forward the sap roller when required to place a fresh gabion, and crowns the gabions with fascines.

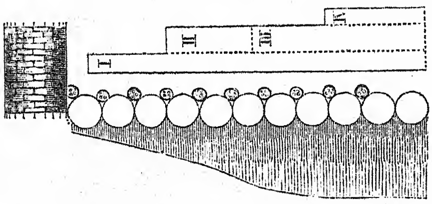
No. 3 deepens the work of No. 2, 18 inches. He helps to push forward the mantlet, if necessary, and assists No. 2 in placing the fascines.

No. 4 widens the trench 10 inches, to the full depth of 3 feet.

These three Nos. throw the earth just outside the gabions placed by No. 1, and hand up to him, when required, the gabions, sand bags, or sap faggots. Each sapper has a length of 5 feet to excavate, but is not restricted to the width given, which may be increased, to occupy the time. The work proceeds at the rate of 10 or 12 feet per hour in easy, and 5 or 6 feet in difficult, soil. Figs. 1 and 2 are the plan and section of the above sap, showing the tasks of the different men.

In widening the sap to a regular trench, the working party may be told off in the proportion of one man to every two or three gabions in the part not occupied by the sappers.

Fig. 1.



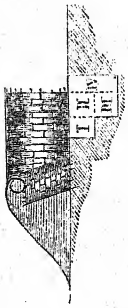


Fig. 2.

The Standing Sap has no banquette, and is 6 inches wider than the common sap. It is excavated by only three men, who work standing, each digging a trench 18 inches wide and 3 feet deep, altogether making a rectangular section of 4 feet 6 inches by 3 feet. Its progress is slower than that of the other sap, being only about 8 feet per hour in easy, and 4 feet in difficult, soil.

Flying Sap.

This is adopted when there is a lull in the fire of the besieged. A few men run out, each carrying two gabions, and place them in continuation of the parapet already formed by single sap. They fill the gabions as rapidly as possible, to obtain cover, and then, if the fire is resumed, move the sap roller forward to the end of the gabions thus filled, and continue the single sap. A similar mode of working has been generally adopted in forming the second parallel of an attack, when the working party of infantry is extended along the proposed line, each man with two gabions, which he places in front of him, and then excavates a trench and fills the gabions as quickly as possible. The trench dug by each man is thus about 4 feet long, 5 feet wide, and 3 feet deep in front, with a berm of 18 inches. Lodgments on the crest of the glacis, and rifle screens for a small detachment, are made in like manner by a few men running out, placing their gabions, and obtaining cover behind them as speedily as possible.

Double Sap.

This sap is employed when it becomes necessary to advance straight on the salient of a work, or when the trenches are exposed on both sides to fire, and it is necessary, therefore, to have a parapet on both sides, and to place returns or traverses alternately right and left, so as to form screens and prevent the trench being seen into. The bottom must never be less than 10 feet wide in the clear, but otherwise the distance of the traverses from one another depends on the command of the work attacked.

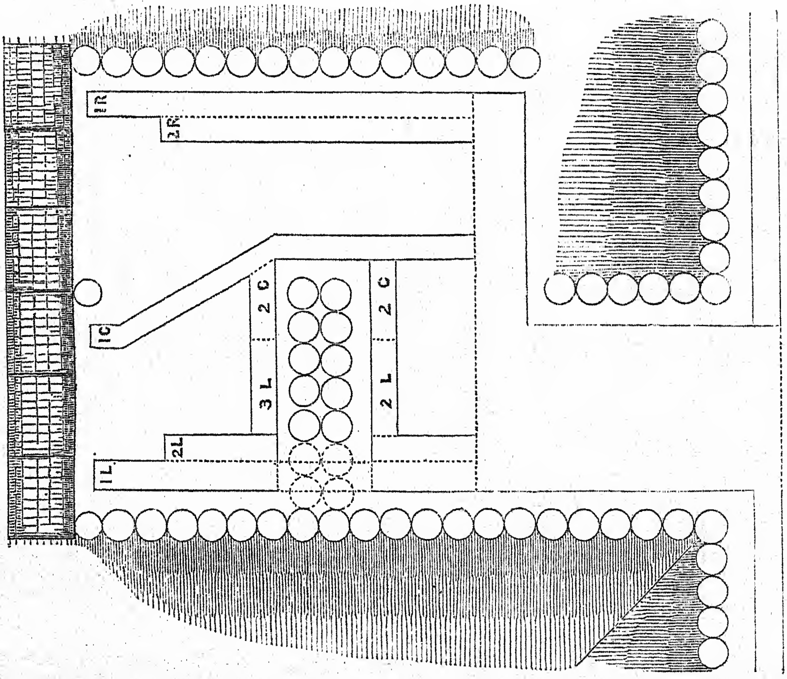
There are three kinds of Double Sap, namely, the Direct, Jebb's, and the Serpentine. The last mentioned is formed in short branches by two squads of sappers working two saps in contact, but having their parapets opposite ways. It is only suitable where guns are not required to be brought up.

The Direct Double Sap requires the following men, tools, and materials, viz. :— 2 N. C. Officers, 9 Sappers, 9 pickaxes, 9 shovels, 3 sap forks (long-handled), 6 ditto (short-handled), 3 measuring rods (4 feet), 1 ditto (10 feet), 3 mallets and a few pickets,

with sap-rollers enough to cover the sap head and at least half a gabion on each side, gabions, sap faggots, or sand bags, and 6 feet fascines as required.

Execution. Having fixed on the spot for the centre of the sap, a party will pull down six gabions so as to leave a clear space of 12 feet to the right or left of that centre gabion according as the first traverse, of which it forms the angle, is to be to the left or right of the sap. The earth is then cleared from this space to the ground level, and thrown into the trench, whence it is removed at once by another working party. The sappers place five gabions to form the end of the traverse, and a like number on the opposite side, and the working party continue to clear away to the level of the bottom of trench, a berm of one foot being left on each side next the gabions, making first of all, rising to the ground level, a ramp, up which three 5-feet, or two 7-feet sap rollers are pushed, and arranged to cover the working party. After excavating to the foot of the parapet to the full depth, three or two more sap rollers are pushed up and placed in line with the others just outside the first traverse. Nos. 1 and 2 of the three squads dig a trench, just in front of the traverse, 2 feet wide and 3 deep, from which they push on their sap heads. Nos. 1 of the right and left squads being at the extremity of the little trench, and No. 1 of the centre, 14 feet from the left berm. Nos. 2 will follow at 5 feet distance, and when they have arrived at 10 feet from the front of first traverse, they place 7 gabions at right angles to the direction of the sap, and 12 feet distant from the gabion of the first traverse. They then

Fig. 3.



work towards one another, filling the gabions, except the two next the parapet. Nos. 1 and 2 of the right squad continue to work forward. No. 2 left then passes through after No. 1, and leaving 6 feet clear, goes on to widen No. 1's work. No. 3 left then

follows, and works to the right to meet No. 2 centre beyond the traverse; they place the 7 gabions forming the other side of the traverse, and fill them, except the two left ones, as before. When the passage is finished round the traverse, No. 3 left blocks up the opening and fills the four gabions with earth from the tongue in the centre.

On arriving at the end of the second traverse, No. 1 centre works to the left obliquely, so as just to clear the end of the third traverse; remembering, as a check, that when the centre sap has advanced 12 feet towards the left, it should be $9\frac{1}{2}$ feet from the left branch. He then saps straight on past the end of the traverse, and when clear, obliques to the right to pass the fourth, and so on. He lays the earth alternately right and left, to screen himself from stray shot. (Fig 3.)

The third traverse is formed by Nos. 2 and 3 right, assisted by No. 2 centre as before, taking care never to close the opening till the communication is established round.

It is to be considered a standing rule that no sapper should continue at work in rear when room can be found for him to work at a more advanced part of the sap.

Colonel Jebb's Double Sap is commenced differently from the Direct, the sap rollers being passed over the parapet before any earth is removed. To do this, the rollers are lashed to strong baulks passing through them all, and then other baulks *about* $6'' \times 5''$, are placed across the trench, so as to rest firmly on the parapet and the top of the reverse slope. Four men then push each sap roller as high up the baulks as possible; two men raise the rear end of each baulk, while six men push the rollers with sap forks, and two others with the 4 N. C. Officers hold on to guy ropes and ease the rollers gently down the slopes of the parapet into their proper places.

The three squads then commence sapping by *kneeling* sap through the parapet, and construct the double sap as before, except that the first traverse has only three gabions in thickness instead of six; and that the centre No. 1 works direct to his front, instead of passing round the end of the traverses; by which course the alternate traverses are cut in two places. The following are the men, tools, and materials required for this sap, viz.:—For passing the sap rollers over the parapet—1 N. C. Officer, 30 Privates, 32 fathoms $1\frac{1}{2}$-in. rope, and 4 pieces of timber for lashing the rollers, 8 baulks $6'' \times 6''$ or $6'' \times 4''$, 4 pickets 4 feet long, and 2 pieces $1\frac{1}{2}$-inch rope each 5 fathoms long, for passing the rollers over.

For the sap itself:—3 N. C. Officers, 12 Sappers, 12 pickaxes, 12 shovels, 3 sap forks (long-handled), 6 ditto (short-handled), 3 measuring rods (4 feet), 1 ditto (10 feet), 6 gauges (18 inches), 3 ditto (20 inches), 3 mallets, and some pickets; sap rollers, sap faggots, gabions, and fascines as before.

C. R. B.

It may be well, while treating of the sap, to refer to those portions of the completion of the attack which are commonly carried out by this mode of working, as they have not been noticed in the previous volumes.

Demi-parallels.

*When the approaches come within easy musket-range of the salients of the covered-way, short parallels, 100 to 150 yards in length, are extended to the right and left from the angles of the zigzags, for the purpose of posting firing parties of infantry to oppose the musketry-fire of the garrison. These are called *Demi-parallels;* they serve also to support the head of the attack when more than halfway from the second parallel to the place, and their extremities afford good positions for Cohorns and royal mortars, which throw shells into the covered-way with very destructive effect. To protect the infantry firing from the trenches, the

* From the printed papers, Royal Military Academy.

parapets are raised by placing sand-bags on them so arranged as to leave loopholes at the proper intervals. During the close attack, the besieger's success will greatly depend on keeping down the musketry-fire of the fortress. To this end, every part of the trenches which admits of it should be made available for musketry, so that, if possible, such an overwhelming fire may be brought against the garrison as to prevent them even pointing a musket over their parapets; and rifle-pits, or screens, are formed in front to hold from 2 to 10 men each. When the approaches arrive near the foot of the glacis, or within 120 yards of the salients of the covered-way, trenches are again carried out to the right and left, which, being extended till they meet, form a *Third Parallel.* This is necessary to connect the heads of the attack, and to establish a secure position where the besieger may collect materials and make other preparations for attacking the covered-way. The besieger's operations being now confined to the salients on which he has been approaching, and the space between them, the third parallel need not be extended on either flank more than 300 yards beyond their capitals.

Third parallel.

Crowning the covered-way.

The operation of forming the lodgments on the crest of the glacis is termed *Crowning the Covered-Way.* This is sometimes done by assault, but only when the defences have been so injured or the garrison is so weak and dispirited as to render success highly probable. Against a strong and spirited garrison, such efforts to hasten the progress of the siege are generally attended with defeat and disaster, and after sacrificing many valuable lives in an unsuccessful assault, the besieger has to resort to the slower but sure process of systematic approach. When it is decided to crown the covered-way by assault, a quantity of materials sufficient to form the lodgments is collected on the reverse of the third parallel, and portions of it on both sides of the capital are formed in steps.

By assault.

When everything is ready, the storming party rush into the covered-way, and drive its defenders into the re-entering places of arms. They are closely followed by a working party, who trace the lodgments, as well as the communications to the parallel, by flying sap, and cover themselves as quickly as possible. When sufficient cover is obtained, the storming party retire into the lodgments, which need not be extended further than necessary to insure possession of the covered-way. When it is intended to proceed by systematic approach, two trenches are broken out by sap from the third parallel, one on each side of the capital about 40 yards from it. These are directed inwards, to meet on the capital about 30 yards from the parallel, forming what is called the *Circular Portion.* From this a double sap is carried on the capital to within about 30 yards of the salient, where saps are pushed to the right and left along the slope of the glacis, about 20 yards beyond the prolongations of the crests of the covered-way, extending somewhat inwards, so as to enclose the salient, and terminating in a return at an obtuse angle, about 8 or 10 yards in length. The parapets of these returns and of about 15 yards of the trench at each end are then raised high enough to command the salient place of arms. From these high parapets, which are caled *Trench Cavaliers,* the besieger's musketry soon forces the garrison to evacuate the salient place of arms. A double sap on the capital, or two single saps from the inner ends of the trench cavaliers, are then pushed forwards to within six yards of the crest of the glacis, where the lodgments are commenced.

By systematic approach.

Though the principles observed in the former part of the attack are adhered to during the subsequent operations, yet their details will vary considerably when applied to fortifications of different constructions. Those, however, who clearly understand the attack of one kind of fortification, will have little difficulty in comprehending the modifications applicable to the other. We will therefore select, as an example, a large

polygon of the French Modern System, which may be considered the ordinary bastioned system in its most improved form. From the great saliency of the ravelins, a besieger must take two of them before he can reach a bastion. We will therefore suppose our attack to have been carried as far as the salient place of arms of two ravelins, it being the besieger's intention to penetrate to the bastion between them.

While the approaches are made from the third parallel on the two ravelins, a double sap is pushed forward on the capital of the bastion, and a fourth parallel is constructed to connect it with the trench cavaliers. The lodgment on the glacis of each ravelin consists of a trench, commenced by double or half-double saps, parallel to the crest, and at a distance of six yards from it, so as to leave a sufficient parapet, to protect which from enfilade and reverse fire from the face of the bastion and the opposite ravelin, traverses are made by single sap at right angles to it. The lodgment on each flank of the attack, being extended as far as the prolongation of the face of the ravelin, is converted into a battery to breach the face of the bastion through the opening afforded by the ditch of the ravelin. The lodgments on the other side are extended as far as the third traverses of the covered way, the double sap is continued on the capital of the bastion as far as the foot of its glacis, and a fifth parallel is constructed, connecting it with the lodgments on either side, which are then converted into batteries to breach the ravelin. While these breaching batteries are constructing, the besieger commences his *descent into the ditch* of each ravelin, by means of a great gallery of a mine extending from the lodgment to the bottom of the ditch. The gallery of descent may be on either side of the breaching battery, but it is better to construct it on the side next the salient, as the ascent of the breach will then be better covered from the fire of the bastion. It should never have less than three feet of earth above its roof; its slope should not be steeper than one in four, and should be so regulated as to reach the bottom of the ditch, when dry, three feet below its surface, to meet the bottom of the trench crossing it. It should enter a wet ditch a foot or two above the level of the water. It will often occur, particularly with wet ditches, that from the inconsiderable height of the counterscarp, the gallery of descent will not have sufficient earth over its roof when passing under the covered-way; in that case it should, if possible, be carried under a traverse, and the passage round the traverse filled up with earth or fascines. Another mode of descending into a ditch is to drive a gallery from the lodgment on the glacis to the back of the counterscarp revetment, and there lodge a charge of powder to breach it. This is called *blowing in* the counterscarp. The breach thus made will form a ramp into the ditch, to which a communication may be made from the lodgment on the glacis.

Lodgment on the glacis.

Breaching batteries.

Descent into the Ditch.

Passage of the ditch when dry.

When the ditch is dry, a passage across it is effected simply by means of a trench made by sap, extending from the opening of the gallery to the foot of the breach, the flank defences being subdued by the battery on the crest of the salient place of arms, assisted by musketry and vertical fire. After the breach has been made practicable, the fire of the breaching battery may be employed to drive the garrison from the summit of the breach, or to destroy a parapet wall or escarp gallery, should such exist on either side of the breach, from whence the garrison might oppose the passage with musketry. The mode of passing a wet ditch will depend on circumstances. When the water is stagnant, a passage may be made without much difficulty, by constructing a causeway of fascines, which should be loaded with stones to make them sink, and a parapet of the same material. The fascines should be passed from hand to hand by men stationed in the gallery for the purpose. Much time would be saved by constructing two galleries of descent, as was done by the French at the siege of Antwerp in 1832, and making use of one of them to build the parapet, and the other the road. When a current of water flows through the ditch of a fortress, the difficulty of passing

Passage of the ditch when wet.

it is very great; and if the stream be deep and rapid, or the garrison have much command of water, so as to be able to empty and fill the ditch at pleasure, the difficulties are almost insurmountable. The passage must be made either by constructing a causeway sufficiently strong and high to retain the water till it finds vent through other channels, or with openings to let the water through; or by means of a floating bridge or raft. The former mode must always be impracticable, unless the height of water to be retained is inconsiderable, in which case a dam might be made with loaded fascines and sand-bags, and openings might be left in the lower part of it for the passage of water, by sinking a frame-work of wood, or casks and large gabions, with their axes in the direction of the current. According to the opinion of Vauban, "there is no other mode of passing which can be depended upon; for to employ trestles, flying bridges, or rafts, it would be impossible to work at them under cover, and there would be found neither security, possibility, nor utility in their construction."* Cormontaigne, however, describes the construction of a floating bridge of fascines, which was employed with perfect success at the siege of Philipsburg in 1734. It consisted of layers of fascines, alternately crossing each other with hurdles between, and fastened together by pickets; its width was 48 feet at bottom, and its thickness 6 feet, with a parapet formed by a double row of gabions, with three or four rows of fascines on them, covered with fresh raw hides, to prevent their being burnt. Two such bridges were constructed in six days, across ditches 20 toises wide, in which there was from 12 to 15 feet of water, with a loss of not more than twenty men at each bridge. The current, however, could not have been rapid, as Philipsburg is situated in a low, marshy country. It has been proposed to strengthen a fascine bridge by laying several rows of beams in it lengthways, with pickets four or five feet long, and pointed at each end, passing through them at intervals of about four feet. At the siege of Freibourg in 1713, by the French under Marshal Villars, owing to the garrison possessing great command of water, the besiegers found much difficulty in effecting the passage, and after thirteen days' work, with a loss of more than 100 men per day, they would have failed altogether had not Marshal Villars contrived to divert the waters of the *Thersein*, which flowed through the town, into another channel.

Lodgment on the summit of the breach.

Marshal Vauban's mode of gaining possession of a breach is, in Sir John Jones's opinion, "so simple, so bloodless, and forms such an advantageous contrast with the open assaults at the sieges detailed in his work, that every one must regret the inability of the army to have followed the same mode of proceeding."† It is, therefore, given as translated from the '*Traité des Sièges*.'

Preparatory to making the lodgment, a great quantity of materials must be provided, such as gabions, fascines, and sand-bags, and also a number of intrenching tools, which should be carried as far forward as possible, without encumbering the trenches, and piled on the reverse of them. Care must be taken that all the lodgments from which it is possible to fire on the part to be attacked are in a perfect state, and that the batteries of cannon, mortars, and pierriers, are in readiness to open; and the officers commanding in the batteries and lodgments should have it fully explained to them on the spot, how they are to act according to the signals made.

Assault of a breach.

"The signal may be from a flag elevated on the lodgment of the covered-way, at such spot as shall be seen from all the batteries and lodgments. Everything being ready, the infantry will place their muskets through the sand-bags laid for their protection on the top of the parapets, and every one will await in silence the signal to open his fire by the flag being hoisted, and to cease firing on its being lowered.

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* Vauban's 'Traité des Sièges,' edited by Colonel Augoyat, p. 157.
† Jones's 'Sieges,' vol. ii. p. 372.

"Thus prepared, two or three sappers will ascend the breach—not up the centre, but on its right and left, next the end of the broken wall, where cover is usually found between the part of the revetment which remains standing and that which has been beaten down. The two or three sappers will lodge themselves in these hollows, throwing the rubbish down, but working upwards, and will procure cover for two or three other sappers, who will be sent to their assistance, the whole being prepared to leave their work on any advance of the enemy. Should that occur, as soon as the sappers are off the breach the signal is made, and all the batteries and lodgments instantly open a heavy fire on the enemy, who cannot remain under it, but will quickly disperse. As soon as that is perceived, the flag must be lowered, and the sappers again sent forward, who, resuming their work, will push it forward as much as possible; again abandoning it, however, whenever the enemy make their appearance, which may occur a second and even a third time. Each time, however, that they do come forward, all the lodgments and batteries, even those of the covered-way, must resume their fire, which cannot fail to drive back the enemy, and give opportunity to establish the lodgment. It will not probably be till the first or second time of returning that the garrison will spring their mines (if there be any), and which may be considered an infallible sign that they give up the work. These mines are unlikely to be attended with any great effect, for they may be sprung at a moment when the workmen are not on the breach; or they may have been formed under the part where the sappers do not work, or at worst can only destroy three or four men. In the mean time the sappers will have prepared some cover in the excavation, which when completely ready, and not till then, must be occupied by small detachments; but as soon as the garrison abandon the work, the lodgment must be made openly in the breach, and be well secured along the whole excavation, but not beyond it. Afterwards the work will be extended to the right and left along the rampart by saps, forming a portion of a circle which will occupy all the terreplein of its flanked angle: from thence it will be carried along the two faces of the work till everything is duly prepared to force the intrenchment at the gorge."

When it is decided to carry a breach by open assault, a heavy fire is directed on its summit and the neighbouring defences, to force the garrison to retire from them. The storming party, which should be of considerable strength, then rush up the breach, followed by a working party with gabions, who trace the lodgment by flying sap into which the storming party retire when sufficient cover is obtained. "Daylight is certainly the best time for storming works, when the troops can advance under cover to the breach or point of escalade, or have the support of a powerful artillery. But when the garrison have preserved an extensive front of fire, and the trenches have not been pushed very forward, to storm in daylight can be seldom advisable, as the troops would most frequently suffer so much in advancing as to be disabled from any serious effort when arrived at the breach. The most preferable time for such open advances is at the moment of daybreak. In the dark, the troops are liable to imaginary terrors, and being concealed from the view of their officers, the bravest only do their duty. When it is decided to assault a place immediately before day-break, the utmost attention should be given on the previous morning to ascertain the exact moment of its becoming light; and the most energetic and decided measures must be taken to insure the columns advancing at the instant fixed upon, as it will be found equally prejudicial to their success to be too soon as to be too late." *

Of the various methods by which the attack may be carried forward against the

* Jones's 'Sieges.'

modern ravelin and redoubt, the following appears as reasonable as any. It may here be observed, that the escarps of redoubts and retrenchments are, under ordinary circumstances, much more easily breached by mine than by guns, for their ditches being generally narrow, and flank defences not formidable, the miner is easily attached; whereas the operation of arming a breaching battery in a narrow outwork is one of extreme difficulty.

Attack of ravelin and redoubt.

The lodgment in the ravelin is extended inwards by cutting small zigzag trenches in the thickness of the parapet, communicating with trenches across the terreplein, which are occupied by musketry to oppose that of the redoubt. If the garrison should be able to maintain a fire of artillery from the face of the bastion for the defence of the ditch of the redoubt, it may be necessary, before attempting a passage, to convert part of this lodgment into a counter-battery to subdue their fire. In the mean time a zigzag trench in the ditch of the ravelin is carried further in to the escarp, and two galleries are commenced to ascend into the ditch of the redoubt, the outer one being a great gallery, and the other one a common gallery. When this last breaks through the counterscarp, a trench being carried across the ditch will enable the besieger to reach the escarp and breach it by a mine. By the time the mine is ready to be fired, the great gallery will break through, and afford a passage to a storming party who may assault the breach under cover of a fire of musketry from the lodgments on the ravelin. Instead of continuing a gallery from the ditch of the ravelin to that of the redoubt, the besieger's miner might stop halfway, and lodge a charge sufficient to overthrow both revetments, making a breach right through the ravelin, affording an easy passage to the ditch of the redoubt, and by filling up a portion of that ditch with rubbish, enable the besieger to cross it more easily.

When the besieger gains possession of the redoubt, the garrison must abandon the coupures of the ravelin, otherwise their retreat would be cut off. The besieger may then, by a zigzag in the ditch of the redoubt, reach the escarp of the coupure, breach it by a mine, and effect a lodgment on it. From thence he takes the redoubt in the re-entering place of arms in reverse, forcing the garrison immediately to retire from it. The lodgment on the glacis of the ravelin is then extended inwards to the re-entering place of arms, the double sap is pushed forwards on the capital of the bastion, and lodgments effected on the crest of its glacis, which are converted into counter-batteries to assist in subduing the fire of the flanks. The ditches of the redoubts in the re-entering places of arms being now without flank defence, the besieger may with little difficulty breach their escarps and counterscarps by mines, and make lodgments in them, which he converts into batteries to breach the bastion. From the ditches of the redoubts he saps along those of the ravelin, from whence he commences the descent into the main ditch. This and the ascent of the breach are made in the mode already described, and a lodgment is thus effected on the terreplein of the bastion. Further operations would depend on the nature of the retrenchment. If it should have a high well-flanked escarp, it might be necessary to breach it by a mine or battering-guns, as before; if its profile were that of a field-work, it might be stormed by filling up its ditch with fascines or bags of hay or wool, or it might in either case be escaladed.

SHOT GARLANDS,* either of iron or wood, are used to retain shot placed on *Defences*, and their dimensions and scantlings are shewn fig. 1. They preserve the shot from deterioration, and it is usual to place a tier of unserviceable shot under the serviceable pile. A *cast-iron grating* added to the shot garlands recently sent from Woolwich, and shown in fig. 2, has been considered as an improvement.

Fig. 1.

Section on E F.

Plan and section of cast-iron shot garlands for 8-inch shells; the ground-tier consisting of unserviceable shot.

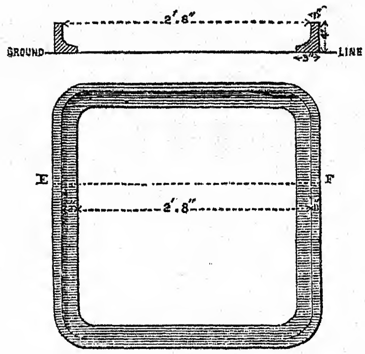
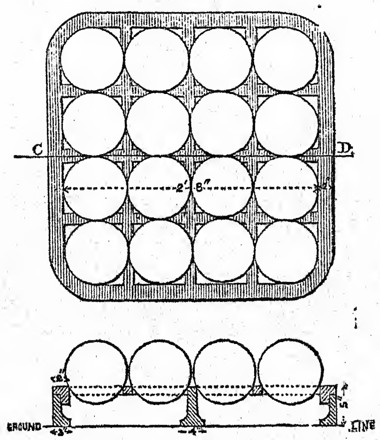


Fig. 2.

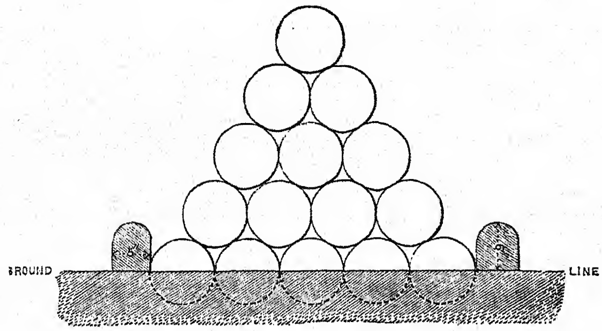
Plan and section of cast-iron shot garlands, showing the proposed gratings for the ground tier, for 8-inch shells.

Section on C D fig. 2.

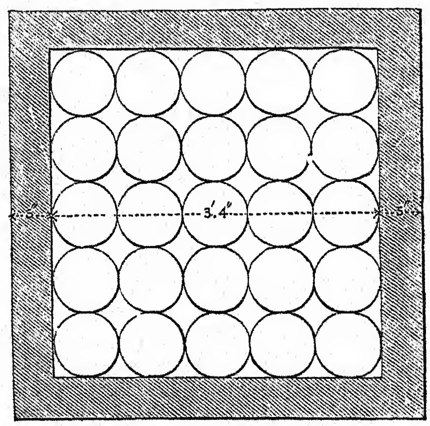


* By Lieutenant-General Oldfield, R.E. and K.H.

Fig. 3.
Plan and section of shot garlands of wood for 8-inch-shells, shewing ground tier of unserviceable shot.



[Fig. 4.



SHRAPNELL SHELLS.*—The Shrapnell is in external appearance like the common shell, but it is made much thinner, and is filled with leaden bullets and a bursting charge; the conditions regarded being :—1st. That the thickness of metal shall be such as to resist the explosion of the charge in the bore of the gun, but to open readily with a small bursting charge; and 2nd. That the bursting charge shall be merely sufficient to open the shell without affecting the flight of the bullets.

In the original Shrapnell, the powder was poured loosely among the bullets; a proceeding which resulted often in premature explosions, caused by friction; but this risk was obviated by the improvement proposed by Lieut.-Col. Boxer, R.A., which consisted in separating the powder from the balls by enclosing it in a metal cylinder, extending from the fuze-hole down the centre of the shell, and filling the interstices between the balls with melted resin, Fig. 1. A much smaller bursting charge is thus required, and the shells can be fired with full service charges, giving a greatly increased velocity and penetration.

* Chiefly from papers by Major Owen, R.A.

THE DIAPHRAGM SHELL (Fig. 2), invented by Lieut.-Col. Boxer has a wrought iron partition which separates the charge from the bullets. The bursting charge is much reduced, and the interstices between the bullets are filled with coal dust instead of resin. In order to facilitate the bursting in a proper manner, four grooves are cast in the interior of the shell. The bullets are composed of lead and antimony, in order to retain their correct spherical form.

Fig. 1.

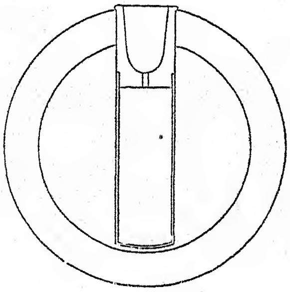
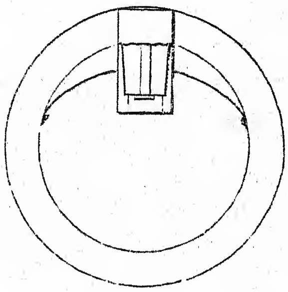
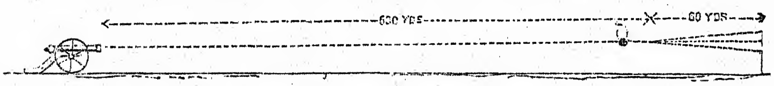


Fig. 2.



These shells are most effective against infantry and cavalry in masses at considerable ranges. The effect produced chiefly depends on the shell bursting at the proper moment, *i. e.* at from 20 to 80 yards short of the object; so that the artillerist should regulate the fuze to cause explosion at about 50 yards short of the object fired at; in order that the balls may not strike the ground first from the fuze being short, nor remain in the shell till it has passed the object, from the fuze being too long.



Ranges of Diaphragm Shells, compiled from Practice.

Nature.	Weight of Gun.	Charge.	Range in Yards. 1000		1100		1200		1300		1400	
		lbs.	Elevation.	Fuze in.	Elevation.	Fuze in.	Elevation.	Fuze in.	Elevation.	Fuze in.	Elevation.	Fuze in.
8-inch	65 cwt.	8	3	·5	$3\frac{1}{2}°$	·6	4°	·7	$4\frac{3}{4}°$	·8	$5\frac{1}{2}°$	·9
32-pr.	56 cwt.	10	2	·4	$2\frac{1}{4}$	·5	$2\frac{5}{8}$	·6	3	·7	$3\frac{1}{2}$	·8

Dimensions, Weight, &c., of Diaphragm Shells.

Nature.	Mean. Diameter.	Mean. Thickness.	Weight. Empty.			Bursters.			Total.			Bullets. Number.	Bullets. Weight.
	inches.	inches.	lb.	oz.	drs.	lb.	oz.	drs.	lb.	oz.	drs.		
8-inch or 68-pr.	7·95	1·026	36	12	...	...	...	60	60	12	...	338	16 to 1 lb.
32-pounder	6·177	0·786	17	8	...	...	...	40	29	3	6	151	
24 ,,	5·595	0·7116	12	13	...	...	...	30	21	2	12	110	
18 ,,	5·099	0·658	9	12	...	...	...	25	16	12	1	77	
12 ,,	4·454	0·567	6	2	...	...	...	20	10	8	4	72	20 to 1 lb.
9 ,,	4·08	0·5167	4	9	...	...	...	15	7	14	1	52	
6 ,,	3·55	0·4556	3	6	...	...	...	10	5	8	8	29	

C. R. B.

SHUTTERS, EMBRASURE.*—The four accompanying sketches are intended to illustrate a method of fitting shutters to embrasures, which is described by Albert Dürer in his book 'Unterricht von Befestigung der Stätte, Schloss, und Flecken,' Nuremburg, 1527. (See Plate.)

These shutters are composed of long spars balanced see-saw fashion on a trestle over the gun, and having a trifling preponderance to the front. Thus, at rest, the fore ends dip to meet the sill of the embrasure (figs. 1 and 3), while the slightest touch behind is sufficient to cant them up (figs. 2 and 4), so as to allow of the piece being discharged, on which the shutter is immediately let fall again. This is a very ingenious suggestion, and seems admirably practical, from the facility with which the shutter is constructed and worked, the promptitude with which a shattered beam could be replaced, and the tendency which the slanting position of the timber would have to deflect a bullet.

SIEGE OPERATIONS IN INDIA.

ATTACK OF FORTS AND FORTRESSES.

PRINCIPLES TO REGULATE THE NATURE OF THE ATTACK.†

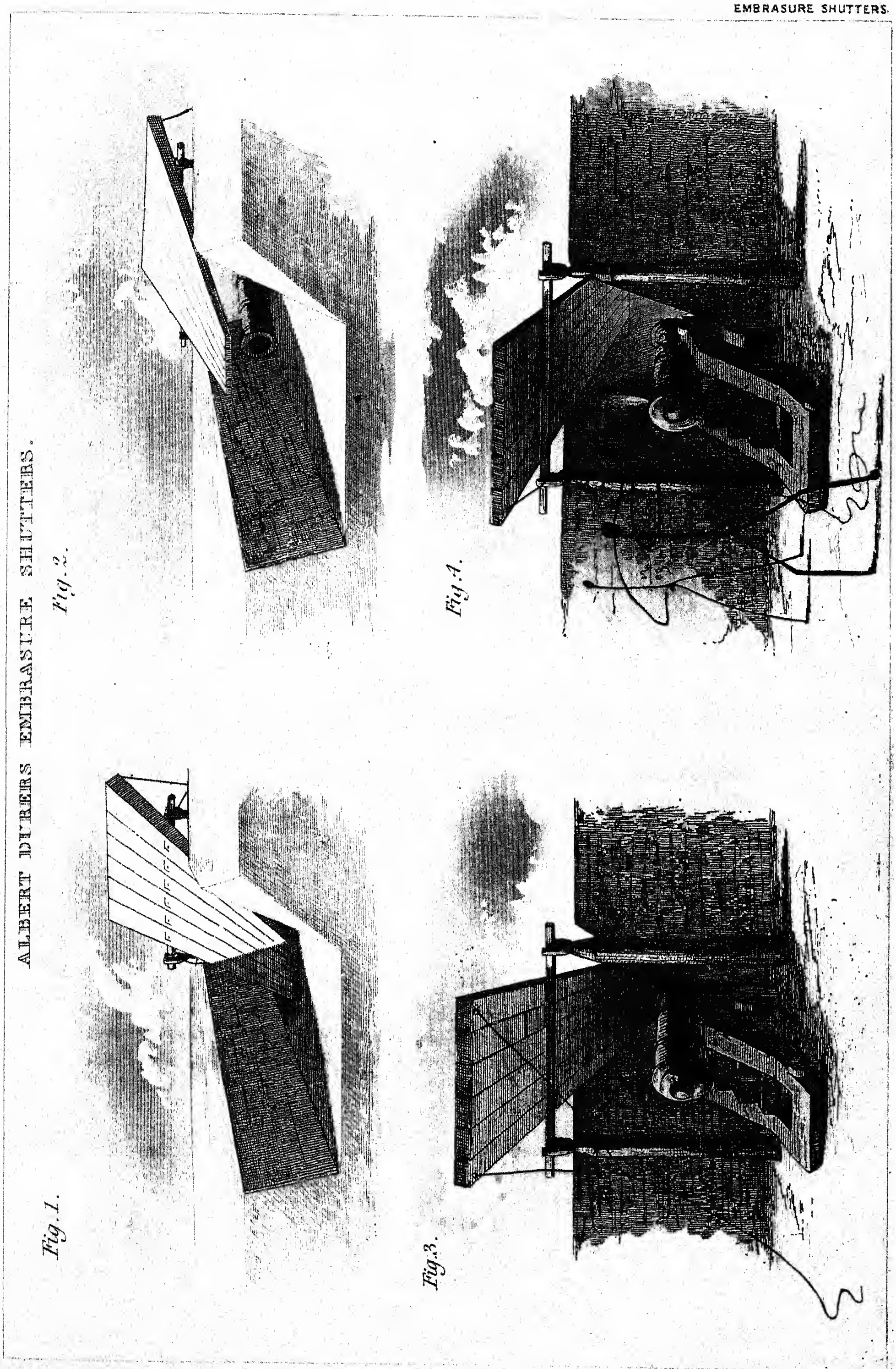
1. In besieging an Indian fortress, it may appear necessary to observe that a salient angle should be chosen as the point of attack; that the pettah (suburb), or any other ground near the place, capable of affording cover, should be occupied, in order to diminish the labour of making parallels and approaches, and that the ricochet batteries should be established, and the approaches pushed on towards the exterior line of works by the flying sap, and continued by the regular sap as soon as that more cautious mode of proceeding is found necessary. These rules, in fact, are precisely the same that would be followed in attacking every fortress, let its nature be what it may; and therefore it is not necessary to enlarge upon this part of the operations, remarking only, in respect to the enfilading fire, that two well-appointed ricochet batteries, placed in the prolongation of these two faces of the fort which form the angle attacked, will generally suffice. By these simple operations, which may be completed in a few days, the besiegers will have advanced to within close musket-shot of the exterior line of defence, after which expert Sappers will be required for executing the regular single or double sap: the progress may be calculated at the rate of three or four yards an hour.

2. At this period of the siege, the peculiar nature of the exterior line of works first begins to influence the operations. Some Indian fortresses have a glacis in front of the main ditch, as at Nowa, which had a partial and imperfect covert way. In the attack of these, the practice of crowning the crest of the glacis by sap must be followed, and batteries may be constructed there for the purpose of breaching the low fausse-bray or rounce-wall which almost invariably surrounds the principal rampart of the body of the place. It is possible, however, that batteries so placed on the crest of the glacis, and firing across a very deep and narrow ditch, may not be able to bear sufficiently low to effect a practicable breach in the scarp revetment of the fausse-bray. In this case, therefore, it may sometimes be proper to blow in the counterscrap and part of the glacis by mining, in order to lay open the fausse-bray to the fire of batteries placed in a more retired situation on the glacis.

3. If, on the contrary, the fortress besieged should have no glacis, but an exterior enclosure, consisting of a simple rampart, beyond the fausse-bray and the main

* By Captain Yule, Bengal Engineers.

† From 'Journals of the Sieges of the Madras Army,' by Colonel Edw. Lake.



J. W. Lowry fc.

London John Weale 59 High Holborn 185[illegible].

ditch, as at Mallijaum, the mode of proceeding must be somewhat different. Whilst the sap is advancing towards this rampart, which is usually of moderate height and constructed of mud, miners must be sent forward to lodge themselves in the lower or solid part of three or four of the principal towers, in which they will prepare chambers for blowing them up. But if this rampart should be built of masonry, then, instead of attaching the miners to the wall at once, it may be necessary to commence the mines requisite for the demolition of the towers by means of galleries carried under the level of the foundation. On the explosion of the mines thus prepared, troops must be in readiness to move forward immediately, and occupy the exterior line of works of the fortress, which will then be laid completely open to assault, and from which, in all probability, the enemy will retire without waiting the issue of a personal conflict. This will form an excellent parallel for the ulterior operations, provided that in certain parts of it a parapet be formed on the reverse of the terreplein towards the enemy, and turning it, as it were, inside out or otherwise.

The next consideration is the passage of the ditch and the formation of a practicable breach in the rounce-wall; for which purpose, if the exterior rampart, now supposed to be in the possession of the assailants, should be too near to the counterscarp to admit of a breaching battery being placed in the interval, it must be cleared away by mines fired for this express purpose. If, on the contrary, there should be a considerable space of ground intervening, this space must be occupied, the sap extended to the brink of the ditch, and a proper breaching battery established, in the same manner as was before described in treating of the attack of the simple glacis or counterscarp.

5. It is possible, however, that under peculiar circumstances it may not be advisable to attempt to breach the fausse-bray by battering guns. In some cases, galleries for the descent of the ditch must be excavated, and the counterscarp revetment pierced; after which the passage of the ditch must be executed by sap, and the rounce-wall or scarp revetment of the fausse-bray must be breached by parties of miners pushed forward for that purpose. At the same time, a battery must be constructed to breach also the high interior line of defence or principal rampart of the body of the place immediately above the breaches in the fausse-bray; and mines must be prepared to blow in the counterscarp opposite to the breaches.

6. The quantity of powder to be used in these mines will depend upon the nature of the counterscarp, and also whether it is revetted. The ditches of native fortresses are frequently without revetments; for the earth in some parts of India is of great tenacity, and notwithstanding the heavy periodical rains, it will stand at a much less slope than in Europe.

7. The explosion should be so timed as to take place as soon as the breaches in the body of the place are practicable, but not before; and the storming party must be in readiness to push forward across the mines the very moment that these are fired, as was done at Nowa, where the explosion of the mines was the signal of assault. These operations, perilous and difficult to men ignorant of such duties, are easy of execution to properly trained Sappers and Miners.

8. In respect to the proper distance for breaching batteries, it may be remarked that even when they are not from circumstances obliged to be advanced to the crest of the glacis or to the counterscarp, it is not recommended that they should be established at more than 150 yards from the wall that is battered. If the ramparts of an Indian fortress are of stone, the curtain should generally be battered in preference to the towers, as the shot are apt to be reflected from the latter, owing to their circular form and the hardness of the material of which they are built. The propriety of this rule was exemplified in a remarkable way at the siege of Palghaut in

1781, when the besiegers in vain attempted to breach one of the round towers of the fort, which was composed of very large blocks of granite, laid in the manner technically called 'headers,' in architecture, so as to present their ends, not their sides, to the shot. In 1790, when the fort was again attacked, one of the curtains was breached in a few hours.

9. If all the works at a fort be constructed of mud, the breaches in each enclosure or line of defence will be better and more quickly effected by mining than by battering-guns; for such is the nature of these earthen revetments, that the shot bury and lodge themselves in the mud without bringing it down. Live shells, the effect of which against earthen works has been proved in Europe to be much greater than that of shot, may be also used to advantage; but it may be justly asserted that there is no country in the world in which mining may be used for the purposes of attack to so much advantage as in India, where the ill-flanked outline enables the miner to lodge himself at once in the face of the rampart, without the necessity of approaching it by galleries, and where the mud of which the works are composed is soft enough to be penetrated with ease, and yet of sufficient tenacity to stand without wood-work of any description.

10. Captain Coventry, of the Madras Engineers, tried an interesting experiment connected with this subject in the year 1811 at Amulnur. It was his intention, in the attack of that fort, to have breached the rampart by mining; but, as the place surrendered without resistance, he resolved, on receiving an order to destroy the works, to put to the test the plan of operation that he had previously determined to pursue if the place had stood a siege. Accordingly he ran a gallery under one of the circular towers, and placed 1100lb. of powder in the chamber, the line of least resistance being 22 feet; and although the powder was of inferior quality, being made by the natives, the effect of the explosion was very considerable, throwing down the whole of the tower and part of the adjacent curtain.

11. It may be remarked that it is better to effect a breach by mining than by battering-guns, so far as regards the expenditure of shot; not so much, however, on account of the expense as the difficulty of conveying a sufficient quantity of this most essential article of store.

12. Even this is a matter of some consequence, if it be considered that it may require three months to convey the shot to the advanced divisions, and that it may be a year or more before they are used; that in the Madras Service they are always transported on bullocks, each of which carries only four 18-pound shot, and involves an expense of nearly five rupees a month, over and above the prime cost of the animal.

13. In regard to the best hour of storming a fortress, after practicable breaches are effected by the battering-gun or by the mine, opinions are divided. The morning, noon, and night have each their advocates.

The storming of Seringapatam took place in the middle of the day; but it appears that the unusual bustle of the preparations in the trenches attracted the notice of several of Tippoo's principal officers, who were fully aware of the intended assault, and requested him to prepare for it,—but in vain,—as a blind fatality seems to have characterised all his actions towards the close of his life and reign.

Orme gives a strong opinion in favour of night attacks. After relating the extraordinary successes of the French under Monsieur Bussey, in 1750, in the assault of Gingee, he observes, that had the attack been made in daylight, it could not have succeeded, for the Moors, as well as Indians, often defend themselves very obstinately behind strong walls; but it should seem that no advantage either of numbers or situation can countervail the terror with which they are struck when attacked at night.

As a general principle it is recommended,—subject, however, to such variations as

local circumstances may require,—to commence the assault in the very early part of the morning, before there is sufficient light for the enemy to distinguish objects correctly. At this time they will also have had the fatigue of watching all night; and to exhaust the garrison the more, a false alarm in the course of the night may previously be resorted to.

APPENDIX I.

*Notes on the Siege of Mooltan.**

1. The second siege was carried through with very little labour to the troops; the amount of trench-work was smaller, and the dangerous part was chiefly executed by the Sappers, the working parties of the Line being employed in widening and improving the previous work. There is no doubt that Brigadier Cheape's project of carrying the suburbs by assault, taking the town, and then prosecuting the attack on the fort or citadel, saved much time and fatigue to the besiegers, which would inevitably have been incurred by the adoption of the attack on the north-east angle of the citadel, without dispossessing the enemy of their cover in the gardens and houses and city walls; and, in all probability, with the city, they would have stood an assault, trusting to make terms in or to secure their flight from the town.

2. The attack from the town after its capture was most judicious, and the breaches on that side would, owing to the destruction of the great mosque magazine on the 30th December, in the upper line of works in the citadel, have been carried with greater ease than those on the north-east: this fact should not be overlooked, the site of a breach in a re-entering angle being deemed objectionable.

Twenty-seven days were occupied in the operations of the second siege. Some of these might, perhaps, have been saved, and it is easy to look back; but considering the necessary loss of life in accelerating the attack, and the difficulties incurred in removing rubbish and clearing houses for the emplacement of batteries and magazines incident to an Indian city, the time that might have been gained is not now worth consideration.

3. As for the details of the siege, the following may be worthy of notice:

The engineers' works were probably too much in advance of the artillery; a more active enemy might have taken advantage of this; and, as a general rule, the defences should be ruined before the sap is commenced. The fort of Mooltan is so far peculiar, that it might be impossible to silence it altogether; but the towers of the advanced line should have been destroyed at an earlier period by the 24-pounders in battery near the Shumstabrez.

4. The artillery practice was most excellent, and the exertions of officers and men indefatigable. It is impossible to overrate the service rendered by the 8-inch and 10-inch howitzers. The walls are mostly of mud, or brick and mud; and it so happened that the part selected for the breach was very defective, a mere facing over the old wall. In this the 24-pounder shot brought down large masses; but where the wall was sound, the shot buried themselves, whereas the shells penetrated, and then acted as small mines. Against a mud fort a howitzer must therefore be considered far preferable to a gun, though of course the latter would be more effective against a well-built stone wall. The inconvenience of howitzers is the difficulty of preserving the cheeks of the embrasures. The iron howitzer might, perhaps with advantage, be lengthened.

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* From Major Siddons' (Bengal Engineers) "Account of the Siege of Mooltan," published in the "Corps Papers" in February, 1850.

5. Lieut. Taylor, Bengal Engineers, who had charge of the engineer park during the siege, contributed greatly to the security of the gunners by the supply of palm-trees roughly squared, which were fixed at the throat of the embrasures, on which shutters of 4-inch planks were hung as mantlets. The only other novelty in the engineering operations was the attempt to construct elevated batteries rapidly by building up the solid portion with fascines nine feet long, of which there was abundance. Four Officers of Engineers and two Sepoy sappers erected a two-gun portion in little more than half an hour, all the material being close at hand; such batteries are, however, highly inflammable, and once on fire, cannot be extinguished, as occurred on the 9th January in one of them.

6. Captain Siddons proposed a field powder-magazine of a new construction; and inasmuch as it might afford sufficient protection against the vertical fire of an Eastern enemy, and would save much expense in the carriage of heavy splinter-proof timber, it might be expedient to experiment and report on it, which could be easily carried out at any station of the army where there is Artillery practice.

7. Nine to ten feet of parapet was found to be ample thickness against the Mooltan artillery.* In a portion of the parallel where the parapet was thinnest, not more than five feet of loose earth, a 14-pounder shot was observed to strike it fully and fairly: it passed through into one side of the revetting gabion, which merely fell over into the trench with the shot inside of it: the distance from the walls was 110 yards.

8. The concussion produced by the salvos from one of the breaching batteries which fired over the trench from which the mining operations were carried on, was very prejudicial to the progress of those works, and the want of casing, in substitution of the old pattern frames and sheeting, was very much felt.

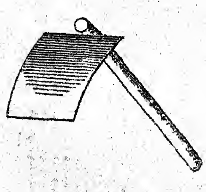
9. No siege was perhaps ever more completely supplied with engineers' stores. The period during which the siege was delayed, pending the arrival of the Bombay Division, was most usefully employed by the Sappers in making up gabions, fascines, pickets, &c., at a town called Shoojahabad, some twenty miles in rear of the army; while Lieut. Taylor, with a singular zeal and ingenuity, prepared all kinds of contrivances for facilitating siege operations, making his park quite a show.

10. The carriage of gabions and fascines to the front was a difficulty, and the fascines were made in lengths of nine feet, instead of eighteen feet, to facilitate this operation, and a proportion of three pickets cut for each fascine. Both fascines and gabions were carried on camels, one camel carrying ten or eleven gabions tied on in an ingenious manner devised by Lieut. Oliphant.

11. The gabions were 20 inches in diameter, and made as light as possible, so that they did not suffer in the carriage, but as 15,000 were made, and 12,000 fascines, no deficiency was experienced. The sap-rollers were made up as near the trenches as possible.

12. Sand-bags were a most useful engineers' store, and were in abundance, but very much wasted by the troops appropriating them to their own use.

13. Phouras are useless constructing tools, and the proportion taken of them might be greatly reduced.



A European soldier cannot work with them at all, and the Sepoy prefers the spade after a couple of hours' practice with it. There is another advantage in giving spades to the Sepoys: they look on them as more of a *military* tool than the phoura used by the labourers of the country, and they therefore are more readily disposed to take them up.

* Probably from the inferiority of the Sikhs' gunpowder.

APPENDIX II.

Extract from a Note by Captain T. W. Hicks, Field Commissary of Ordnance, Bombay Division, April 8, 1849.

1st. Our siege-train platforms are *Bombay*, not Madras, and were invented by the late Major Millar of the Bombay Artillery. No platform can be better for siege ordnance : these platforms, during the siege of Mooltan, did not receive fair treatment, for various reasons, but chiefly owing to my heavy ordnance carriages being half Bengal and half Bombay pattern: the former are made wider in the axle-tree than the latter. Each platform was made to fit its carriage, and the component parts were numbered to correspond with the number on its own carriage; yet, consequent on the batteries being formed at night, there were frequent mistakes, the narrow carriages being put on the wide platform, and *vice versâ*. The platforms we used for the 8-inch howitzers are Bengal patterns, which were left in and brought up by me from the Sukher Arsenal; we hope never to see more of them. The Bengal 10 and 8 inch mortar platforms are, I think, perfect; most easily put together, and comparatively light. We hope they may be introduced in our Presidency.

2nd. Your siege-train carriages are better than ours, owing to the axle-trees being wide, felloes much wider, limber-wheels lower than the gun-wheels, consequently the gun travels on its own carriage with facility; the weight is equal. Our heavy ordnance carriages are too slight. Although the guns may be moved back to travelling-holes, yet all the weight is on the axle-tree; the muzzle of the gun is so low that elephants cannot be used to shove it on. I hope to see our heavy ordnance carriages improved.

3rd. 8 and 10 inch brass mortars have long been abolished, yet this description of ordnance was years ago sent up to Scinde, and, for want of iron ones, these were brought on for service.

APPENDIX III.

During the siege of Mooltan, the Bengal artillerymen were so few that it was found impossible to afford a relief in the batteries without withdrawing gunners from the troops of horse artillery. A relief, however, was thus effected daily between three and four P.M.; which was found the most convenient hour as it afforded time to the relieving officer to ascertain his range, &c. before nightfall, and to prepare and fix his ammunition for expenditure during the night. It was convenient also for the men in other respects.

In the howitzer batteries, it was the practice to receive the charge ready weighed out from the magazine; but in the mortar batteries the charges were invariably weighed out in battery. The bursting charges of all shells were received in battery ready weighed out in small bags, and the shells were always filled by means of a funnel, and fuzes prepared and set by means of a fuze-bench in the battery. Live shells were never sent down to battery from the magazine; as no advantage in point of time was to be gained thereby, the preparing of shells being found, in the hands of expert men, to fully keep pace with the working of the ordnance.

The practice was thus rendered very much more satisfactory, as the length of the fuze could be altered according to circumstances, such as the variation of strength of powder, which was found to be most dependent on the state of the weather, and even of the ordnance, which, as the day advanced, would gradually warm, contracting the dampness of the powder, and rendering necessary an alteration in the length of fuze.

The effects of the howitzers employed in breaching was a subject of satisfaction and astonishment to all; indeed it is doubtful whether the natural mounds of the fort would have been practically breached without their aid. Even against the brick-work their effects were conspicuous. These shells, made to burst at the moment of contact with the walls, afterwards during their passage through the revetment, and ultimately with a longer fuze in the earth beyond it, would probably (against such masonry) have alone effected practicable breaches without the assistance of heavy guns.

At a distance of 150 yards both the 8-inch and 10-inch howitzers were employed in breaching a scarp wall, part of which was invisible from the battery, and only reached by a plunging fire, obtained by my small charges, and succeeded admirably. At a distance of 35 yards, 8-inch howitzers were similarly employed with a charge of 8 oz.; a very low velocity being requisite to prevent the shell from burying itself too far in the soft earth. Of the effects of the vertical fire, nothing could have afforded a clearer proof than the ruinous appearance presented by the interior of the fort on its surrender; and the explosion of the great magazine, which took place within one hour of its site being indicated to the batteries, was a subject of congratulation to the Bengal artillery employed, bearing testimony as it did to the accuracy of their practice.

On the 9th January, 600 shells were fired from an 8-inch mortar battery of six pieces in twenty-four hours, and the mortars did not suffer. No new feature, however, presented itself from the employment of these pieces, nor from that of the heavy guns, which, however, vied with the mortars and howitzers in utility: doubtless it is by a judicious combination of the three that such powerful effects are produced; but it may be worth inquiring whether, in the siege-trains employed against fortresses in the East, built, as they generally are, of old and often crazy materials, a greater proportion of howitzers might not be used with advantage in cases where no particular object exists to curtail the transport of the shells, which is doubtless great. In addition to what has been above stated of the effects of these most useful pieces in mining the defences, and in counter-battery, which was conspicuous throughout the siege, it may be remarked that one shell was often found sufficient to silence the fire from an embrasure of the enemy for a whole day.

Rack-lashing platforms were used by the Bengal artillery throughout the siege for the guns and howitzers, and were found to answer most satisfactorily; and the small Bengal mortar platforms, consisting of three sleepers upon which seven strong planks, each four feet long, were pegged transversely, were made up in the park, and thus taken down to the batteries, where they were expeditiously laid, and stood the firing both of the 8-inch and 10-inch mortars without renewal during the siege; the only difference being that for the 10-inch mortars other sleepers were laid transversely beneath, to prevent the platforms sinking.

D. Newall, Lieut.-adjt. Bengal Foot Artillery, Mooltan Field Forces.

APPENDIX IV.

Return of Engineers' Stores (Bengal and Bombay) expended during the Siege of Mooltan, from September 7, 1848, *to January* 22, 1849.

Letter.	Names of Stores.	Number expended.	Letter.	Names of Stores.	Number expended.
A	Augurs, carpenters,' of sizes	5		Ladles, dammering	1
	Axes, pick, with helves	1153		Lamps, mining, tin	10
	——— helves, spare	1199		Lanterns, dark	8
	—— felling, with helves	200		——— horn	4
	——— helves, spare	186		Lashing, country, for camel slings,	
	—— pick, sap, with helves	6		yards	2000
	——— miners', ditto	2		Lead, pig . . . . lbs.	3
	——— helves, spare	2		Levels, of all sorts	2
	—— push	2		——— universal, with box	1
	—— pole	2		Line, country, log . . skein	1
B	Bags, sand	35,304		——— seizing . skeins	1200
	Bamboos . . . . bundles	36		——— . pieces	34
	——— large	166	M	Mallets, large	56
	——— medium	500		——— small	151
	——— small	75		Mantlets, 6′ × 5″ × 3″, wooden	7
	Baskets, wicker hand	57		Match, slow . . . skeins	4
	Bills, hand and hook	70		——— . . . . . lbs.	2
	Borax . . . . . lbs.	2		——— quick	3
	Borers, jumper	3		Mamooties, with helves	340
	——— hand, two feet	6		——— without ditto	340
	Buckets, wooden water	9		——— helves, spare	440
	——— canvas, miners'	11		Mining stanchions, 7 feet	30
	Barrows, hand, bamboo	6		——— 5 feet	40
C	Cakes of Indian ink	1		——— 3 feet	20
	Candles, wax . . . . lbs.	48		——— 4 feet	40
	Chalk, European . . . lbs.	7		——— cap and ground sills, 4 feet	28
	Charcoal, about . . . lbs.	16,000		——— 3 feet	25
	Chains, measuring 100 feet	1		——— $2\frac{3}{4}$ feet	20
	Chisels, trimmer, carpenters'	1		——— $2\frac{1}{4}$ feet	20
	——— smiths', of sorts	1		——— frames and shaft, complete	8
	Cloth, canvas, European, fine, yds.	10		——— and descending gallery	1
	——— dosottee, white . pieces	30		——— top shaft, com-	
	Cotton . . . maunds, about	200		plete	4
F	Fascines, each 9 ft. long, about	8000		——— planks, sheeting	40
	——— pickets, about	4000		Moonge . . . . maunds	3
G	Glue . . . . . lbs.	3	N	Nails, of sorts, about . lbs	200
	Gabions	10,000		Needles, packing	5
	Gauges, gabion	12		——— sail and sewing	200
	Gunny, single, new . pieces	178	O	Oil, cocoa-nut . . . gallons	2
H	Hammers, hand, for boring bars	13		—— mustard . . . seers	$6\frac{1}{2}$
	——— smiths'	2	P	Palms, steel	5
	——— sledge	6		Paulins, waxed, small	20
	Hatchets, hand, with helves	25		Paper, Serampore . . sheets	4
	Hides, bullock, dressed	6		——— foolscap . . quires	8
	——— half-dressed	204		Pencils, lead, H H H	10
	——— raw . about	300		Pincers	6
	——— sheep, raw	50		Planks, fir, 15 feet long	155
I	Iron, raw . . . . . lbs.	$3331\frac{1}{2}$		Portfires	25
	—— hoop . . . . lbs.	10		Powder . . . . . lbs.	7200
J	Jumpers, iron	1		——— magazine frames, large	9
K	Knives, laboratory	20		——— small	6
	——— gabion	8		Planks, sheeting, seesoo, small,	
L	Ladders, royal patent . pieces	2		(superficial feet)	6
	——— bamboo	16	R	Racks, tool, camel . . pairs	2
	——— scaling joints	3		Rods, measuring, 10 feet	10

RETURN OF ENGINEERS' STORES—*continued.*

Letter.	Names of Stores.	Number expended.	Letter.	Names of Stores.	Number expended.
	Rods, measuring 6 feet . .	2		Twine, country, hemp . lbs.	206
	——— 3 feet . .	11		Timbers, splinter-proof, 8 feet .	171
	——— 2 feet . .	1		——— 12 feet .	63
	Rope, white, two-inch . fathoms	50	W	Wax, bees' . . . . lb.	$\frac{1}{4}$
S	Sap-forks, long	3		Windlass, mining	3
	Saws, with frames . . .	1		Wood, baboot . . pieces	419
	——— tenon, carpenters' . .	1		——— seesoo . . pieces	643
	——— cross-cut	1		——— planks, 3-inch seesoo . .	10
	——— hand	31		——— 2-inch seesoo .	113
	Saucisson . . . . yards	300			
	Scoops, miners'	6		PACKAGE.	
	Screws, small	10	C	Cases, packing, common, large, of	
	——— of sorts . . . lbs.	11		sorts	3
	——— spare	1		——— small, of	
	Shovels, with helves	276		sorts	4
	——— helves, spare . . .	80		Camel bags, old	69
	——— mining, with helves .	10		Cloth, linen, old . . yards	10
	——— sap, with helves . .	24		——— wax, old . . yards	30
	Slings, camel	100		Cotton wick . . . . lb.	1
	Spades	50	G	Gunny, single, old . yards	100
	Spirits of wine . . gallon	1	H	Hemp, country or jute . lbs.	4
	Steel . . . . . lbs.	$8\frac{1}{2}$	L	Lashing, country . . lbs.	48
	Stones, grinding, medium . .	1		Line, seizing, country . . pieces	34
	——— troughs . .	1	N	Nails, iron, of sorts . lbs.	3
	Spikes, jagged for guns . . .	330	P	Paper, packing . . quires	4
T	Tape, common . . bundles	$10\frac{1}{2}$	R	Rope, jute . . . . cwts.	25 2 10
	——— Newar, $1\frac{1}{2}$-inch . . yards	5500	T	Twine, country, No. 3 . lbs.	20
	Thread, cotton . . lbs.	23			

(Signed) ALEXANDER TAYLOR, Lieut., late in Charge of Engineers' Park with Mooltan Field Force.

APPENDIX V.

Expenditure of Shot and Shell during the Operations before Mooltan.

Goojrat, March 4, 1849.

Bengal.	First Operations.	Second Operations.	Total.
24-pounder round shot	...	4386	4386
18-pounder ditto	400	5011	5411
24-pounder case shot	...	...	...
24-pounder Shrapnell shell	...	...	...
18-pounder ditto	150	4	159
18-pounder case shell	...	314	314
10-inch common shell	...	3450	3450
10-inch case shot	...	1	1
8-inch common shell	496	7189	7685
$5\frac{1}{2}$-inch ditto	160	2918	3078
$5\frac{1}{2}$-inch light-balls	...	50	50
68-pounder Shrapnell shell	100	20	120
8-inch case shot	8	38	46
8-inch carcases	...	102	102
$5\frac{1}{2}$-inch ditto	...	30	30

(Signed) T. CHRISTIE, Lieut., Commissary of Ordnance, Mooltan Siege Train.

N.B.—Powder expended :—Ordnance . . . . . 85,331 lbs.
Musketry . . . . . 20,530 ,,

APPENDIX VI.

Expenditure of Shot and Shell during the Operations before Mooltan.

Mooltan, February 5, 1849.

Bombay.	First Operations.	Second Operations.	Total.
18-pounder round shot	...	3751	3751
18-pounder case shot	...	206	206
8-inch Shrapnell Shell	...	160	260
$5\frac{1}{2}$-inch or 24-pounder ditto	...	552	552
$4\frac{2}{5}$-inch or 12-pounder ditto	...	290	290
$4\frac{2}{5}$-inch or 9-pounder ditto	...	106	106
10-inch common shell	...	474	474
8-inch ditto	...	6075	6075
$5\frac{1}{2}$-inch ditto	...	1876	1876
$4\frac{2}{5}$-inch carcases	..	10	10
8-inch case shot	...	52	52
Hand-grenades	...	680	680
Also various kinds from brass field-guns employed in the batteries	...	2582	2582

From a paper supplied by Captain T. M. Hicks, Field Commissary of Ordnance, Bombay Division.

N.B.—Powder expended . . . . . . 56,900 lbs.

APPENDIX VII.

Return of Siege Ordnance in battering Mooltan.

BENGAL.

Description.	No. of Pieces.
24-pounder guns	6
18-pounder ditto	6
10-inch howitzers	3
8-inch ditto	4
10-inch mortars	3
8-inch ditto	6
$5\frac{1}{2}$-inch mortars, brass	4
Total number of Bengal pieces	32

BOMBAY.

Description.	No. of Pieces.
18-pounder guns	8
8-inch howitzers	4
10-inch mortars, brass	2
8-inch ditto ditto	6
8-inch ditto iron	4
$5\frac{1}{2}$-inch mortars, brass	11
Total number of Bombay pieces	35

PROPORTION OF ORDNANCE EMPLOYED.

Guns	20
Howitzers	11
Heavy mortars	21
Light ditto	15
Total	67 *

* Exclusive of field artillery.

Table of Stores required for an Engineer Park, to accompany a Siege Train consisting of 8 or 10 guns and from 16 to 20 mortars.

Letter.	Description of Stores.	Number of each.	Weight of each.	Purpose for which required.
			lbs.	
A	Axes, felling, with helves complete	300	$6\frac{3}{4}$	Cutting down trees, brushwood, enemies' defences, &c.
	——— helves, spare	75	$1\frac{3}{4}$	
	—— pick, common, with helves	1000	6	Intrenching and sapping. N. B. — Those in store weigh sometimes from 8 to 10 lbs.
	——— helves, spare	259	$1\frac{3}{4}$	
	——— mining, with helves	20	2	Mining in earth and masonry.
B	Bags, sand	30,000	2	12,000 for revetting and repairing batteries, 7000 loading and tamping mines, 6000 making loopholes and sapping, and 500 spare.—N.B. On rocky ground, 50,000.
	Bamboos, large	200	60	For scaling-ladders.
	——— hollow	100	15	For casing tubes.
	——— small	17,000	2	10,000 for making pickets for 2000 gabions, 2000 for 5000 fascine pickets, &c., and 5000 spare.
	Barrows, truck	6	55	Driving, tamping, and loading mines.
	Barrels, budge	3	$18\frac{1}{2}$	In mining, for carrying filled hose, quick-match, &c.
	Baskets, wicker hand	4000	$1\frac{1}{2}$	In mining, making batteries and other field-works.
	Bellows, mining	4	...	For ventilating mines.
	——— smiths', medium size, with frames complete	2	240	For two smiths' forges.
	Bill-hooks	2000	$2\frac{1}{2}$	Cutting brushwood, making fascines, gabions, &c.
	Borax . . . lbs.	...	2	Repairing tools and stores.
	Borer, earth	1	100	In mining, for making ventilating holes, &c.
	Buckets, wooden.	40	9	Holding water to extinguish fires, baling water out of mines, &c.
C	Candles, wax. . lbs.	...	100	Lighting mines, &c.
	Chains, measuring (100 or 50 feet)	4	20 or 35	Measuring mines, trenches, &c.
	Charcoal . . lbs.	..	100	Making and repairing tools.
	Chevaux-de-frise . feet	1000	...	Protecting the flanks and rear of field-works.
	Cloth, waxed, yards, 50, or pieces	5	$3\frac{1}{4}$	Covering bags of powder in loading mines, &c.
	Compass, box, mining	2	...	In mining and tracing field-works.
	Crows, iron, large and small	10	36 & 25	Breaking down defences, mining in masonry, &c.
F	Flags, park, with staff, &c., complete	1	100	Distinguishing the engineer park.
	Forks, sap, long	20	$9\frac{1}{2}$	Sapping, and for setting up scaling-ladders.
G	Gauges, gabion	50	7	Making gabions.
	Ghee . . . . lbs.	...	400	Burning in the mines.

STORES REQUIRED FOR AN ENGINEER PARK—*continued.*

Letter.	Description of Stores.	Number of each.	Weight of each.	Purpose for which required.
			lbs.	
	Gunny, $3\frac{1}{2} \times 2\frac{3}{4}$ yds., pieces	100	3	Making cotton bags, covering backs of scaling-ladders, &c.
H	Hatchets, hand, with helves	100	$2\frac{1}{3}$	Cutting thick brushwood, large pickets, &c.
	——— helves spare	20	$1\frac{1}{2}$	
	Hammers, sledge	6	25	Breaking stones and removing obstructions.
	Hooks, sap, long and short	10	$9\frac{1}{2}$ & $4\frac{1}{2}$	In sapping.
I	Iron, bar, European	...	400	Making and repairing tools and stores.
	——— country	...	200	
K	Knives, laboratory	100	$\frac{1}{5}$	Cutting string, &c.
L	Lanterns, dark	10	1	Loading mines, serving out tools and stores at night.
	——— horn	12	2	
	Lamps, mining	40	$\frac{1}{2}$	Lighting mines.
	Levels, ground, squares and bevels, of sorts, with bobs	12	5 to 10	In mining, and tracing, levelling, and revetting field-works.
	Line, country, seizing skeins (50 yards)	50	$3\frac{3}{4}$	Tying scaling-ladders, making rope, &c.
	——— log, bundles (50 yards)	100	$1\frac{1}{5}$	Tracing.
	——— park, feet	1000	140	Marking boundary of engineer park.
	Linen, dosottee, pieces	30	$3\frac{3}{4}$	Making hose.
M	Mallets, large	50	20	Driving large pickets.
	——— small	300	6	Driving tracing and other small pickets.
	Match, slow, country, bundles	4	1	Lighting mines.
	——— quick	10	10	Ditto ditto.
	Mamooties, with helves	2000	7	Intrenching, &c.
	——— helves, spare	500	$1\frac{1}{2}$	Replacing broken ones and making fascines.
	Measures, powder, large and small	4	6 & 4	Measuring powder.
N	Needles, sail and sewing	200	...	Making hose, cotton bags, &c.
	Nails, of sorts	...	50	Making mining-tubes, boxes, &c.
O	Oil, mustard . gallons	3	8	Cleaning and preserving tools and stores.
P	Palms, steel	20	...	Sewing.
	Pickets, park	100	12	Marking the boundary of the park.
	Picks, pushing	20	2	Mining.
	——— ventilating, 400 ft.	100	...	Ventilating mines.
	Planks, $\frac{1}{2}$ in. thick, and from 4 to 12 ft. long	200	10 to 30	Profiling, mining, &c.
	——— $1\frac{1}{2}$ in. thick, and from 4 to 8 ft. long	600	30 to 60	Making mine sheeting and framing.
	——— Saul, $2\frac{1}{2}$ inches thick, and from 4 to 12 feet long	120	150	Making powder-magazines.
	Portfires	15	1	Firing mines.
	Powder, ordnance	...	5000	Ditto.
R	Rammers, earth	100	$15\frac{1}{2}$	Making field-works.
	Ratans, 10,000, or bundles	100	15	Tying fascines and making light gabions.

STORES REQUIRED FOR AN ENGINEER PARK—*continued.*

Letter.	Description of Stores.	Number of each.	Weight of each.	Purpose for which required.
			lbs.	
	Reels, camp, with lines	5	20	Tracing.
	Rope, jute, skeins of 30 yds.	1500	$2\frac{1}{2}$	Tying fascines, &c.
	Rods, measuring, 10 feet	50	$3\frac{1}{2}$	Tracing, sapping, and mining.
	——— 3 feet	50	1	
	——— 2 feet	20	$\frac{2}{3}$	
S	Saws, cross-cut	2	16	Cutting up timbers.
	—— hand	30	2	Cutting up fascines, &c.
	Shovels	1000	$4\frac{1}{2}$	Sapping and intrenching.
	——— helves, spare	250	2	
	——— mining	50	4	Mining.
	Spades	50	$5\frac{3}{4}$	Intrenching and cutting sods.
	Spirits of wine gallon	1	7	Mining.
	Steel	...	10	Making and repairing tools.
	Stones, grinding, with troughs	2	200 or 300	Sharpening and repairing tools.
	Scales, large, with triangle, &c.	1	204	Weighing stores.
	——— medium, copper	1	$13\frac{1}{2}$	
	Spars, Saul, 4 in. square, and 6 to 10 feet long	60	40 to 67	Making mine-frames; making and repairing tools and stores.
	——— 6 in. square, and 12 feet long	40	180	
T	Tape, Newar, yards	2000	300	Tracing at night.
	Tallow	...	50	Preserving stores, greasing truck-wheels, &c.
	Tarpaulins, 17×11 feet	30	76	Protecting stores from the weather and powder from damp.
	Tent, laboratory, large	1	1120	Preserving stores from the weather.
	——— small	1	1019	
	Tin, sheets	25	1	Making and repairing ventilating-tubes.
	Thread, cotton, coarse	...	40	For lamp-wicks.
	——— sewing	...	20	Making hose, &c.
	Twine, country, hemp	...	20	Sewing gunny, &c.
	——— moonge	...	4000	Tying casing-tubes, making gabions, &c.
	Tools, carpenters' chest	1	188	Making and repairing tools and stores.
	—— blacksmiths' chest	1	332	
	—— mining chests	2	518	Mining in rock and masonry. N.B. The new sets of tools.
W	Wax, bees'	1	1	For the use of the tailors.
	Weights, brass set	1	2	For weighing small articles of store.
	——— iron set	1	168	For weighing large articles of store.

(Signed) JOSEPH TAYLOR, Major.
W. R. FITZGERALD, Captain.
J. THOMSON, Captain.

SIEGE, IRREGULAR.*—An irregular or accelerated attack (*attaque brusque*) is one in which the tedious forms prescribed for the reduction of fortresses are wholly or in part dispensed with, and much judgment is required in the General and the Engineer to know when it may be applied with effect; that is, to reject each form in precise proportion to the defects of the place or the force of circumstances, and no further; for there must be more or less risk of failure in operations so conducted, if applied in excess, whereas nothing ought to be more certain than the result of those that are conducted on regular Siege principles.

Two leading causes may justify such an accelerated attack:

I. Defects in the fortifications, or in the state of the garrison and its supplies, admitting of a voluntary and reasonable course of proceeding for shortening the operation.

II. The force of circumstances in the condition of the army attempting the reduction of the place, which may oblige the Commanding General to an irregular proceeding that would be otherwise unjustifiable.

Nothing can be more precise than the principles for the reduction of any fortress, and nothing more imprudent than to deviate from them unnecessarily; but the ordinary *rules* deduced from those *principles* assume the fortifications to be well provided with everything requisite for a good defence.

In proportion as either of these are defective, the regular forms that otherwise would be required may be dispensed with. The following are among the cases in which advantage may be taken of these defects:

1. Treachery, or very culpable negligence on the part of the garrison, may admit of a place being taken by surprise; but this may happen to the strongest and best provided fortress, and is not meant to be treated of in this article.

2. A General may be frequently justified in making an assault by escalade, where a place is under a combination of any of the following risks: if it has escarps not exceeding 24 feet in height, or wholly or in part unflanked, no revetted outworks, nor a wet ditch, or a garrison extremely weak in number, in proportion to the extent of the enceinte.

3. If the fort or fortress is of small interior capacity, unprovided with adequate bomb-proof cover, and the attacking force is well supplied with artillery and projectiles, particularly with mortars and shells, it is frequently to be reduced by bombardment alone. Large populous towns have been reduced by a general bombardment directed on the houses, lives, and property of the inhabitants; but this is an unmilitary proceeding, and in modern days considered an unjustifiable course, frequently resisted with success, when the assailant will be compelled to retire with odium as well as disgrace.

4. The rules laid down for siege operations comprise a variety of works and proceedings for surmounting the distinct impediments that are presumed to exist for the purpose of retarding the besiegers. In proportion as the garrison shall be without the means of applying those impediments, the works defined to overcome them will become unnecessary. Thus, if the strength or composition of the garrison or the nature of the ground will prevent sorties, such part of the parallels as serve for the guard and defence of the trenches will become superfluous; and for the same reason the first works may be greatly advanced, for the fire of the artillery will not prevent the trenches being opened and established very near the place. Again, if the escarps of the body of the place are exposed low enough to be effectively breached from a

* By General Sir John F. Burgoyne, Bart., G.C.B. and R.E.

distance, the serious difficulty and delay of establishing breaching batteries, very close, may be avoided; and if connected with this disadvantage, the breaches so formed have at the time no available flanks, and are not covered by outworks, or only by such as are very imperfect; the advance of the storming parties may be also from a distance. Although the breaches may be opened from a distance, it will not be done until the besieger is in a position to storm them as soon as they become practicable.

5. Again, if the garrison is very short of artillery and ammunition, great liberties may be taken in the progress of the siege.

Advantage ought to be taken of all such circumstances as above enumerated, under any condition of the army of attack,—using judgment and consideration, however, as to the extent to which deviations from ordinary practice may be justifiable.

Occasions, however, arise where a General has only the alternative of attempting these irregular operations against fortifications not strictly exposed to them, or of foregoing important advantages that would be open to him by the reduction of the places.

He may be essentially wanting in the necessary equipment for the siege in form, in quality, in quantity, or in all these; or he may not be master of the proper season, or not possess a knowledge of a power in the enemy to bring against him a sufficient army to oblige him to raise the siege, before the period upon which he can reasonably calculate as necessary for the termination of the process of a regular siege. In these cases he must well calculate his means and the consequences of the enterprise, which may be—

1. The time and sacrifices that will probably be required by the most energetic proceedings it is in his power to adopt.

2. The probability of success or failure.

3. The consequences in either case, or of the alternative of the more cautious system of not making the attempt at all.

No more striking illustrations of operations of this character can be given than those of the sieges in the Peninsula by the Duke of Wellington,—all of them, by the force of circumstances, carried on necessarily against both *rule and principle*. In some, time could not be given for a siege in form; in most, there was a deficiency of artillery means, owing to the difficulty of transport in that country; and in all, the Engineer departments in organization and means were thoroughly inefficient. In Jones's 'Sieges' will be found many interesting lessons in these irregular attacks of places, exhibiting their hazardous character, and how success was so often obtained solely by the admirable dispositions of the General commanding, the zeal and devotion of the Officers of the Ordnance Corps, and the energy of the troops.

J. F. B.

SIEGE AND ENGINEER EQUIPMENT.—This subject is now again under consideration in order to perfect the necessary arrangements for the transport of engineer stores, &c. As a result of the late war, there is now an engineer-train, with waggons, as a nucleus for further operations; but to be really effective it requires to be very largely augmented, and some changes introduced in the organisation. All the stores required by the engineers,—except the tools for ordinary working parties, which should be carried in bulk,—including a complete pontoon-train, similar to that recommended by Captain Fowke, R.E., should be conveyed with the force by the engineer-train, well-horsed, so as to ensure their keeping up; and the waggons for a company should be so arranged that the men of the company may, if necessary, be

carried upon them in rapid movements. The present arrangement gives six waggons and one forge cart per company of 120 men, divided as follows :—

Sergeants	6	All trained artificers.	Carpenters	26
Corporals	6		Masons	22
Second ditto	6		Bricklayers	11
Sappers	100		Smiths	9
Buglers	2		Wheelers	3
			Coopers	1
	120		Painters	7
			Tailors	4
			Collar-makers	3
			Miners	14
				100 Sappers.

Distribution of Tools, Materials, &c., to each Waggon, for a Company of Royal Engineers in the Field.

Description of Articles.	No. for each Company.	Waggons.						Forge Cart.	Remarks.
		1	2	3	4	5	6		
Carpenters' tools, including nails, &c.	5	1	1	1	1	1			
Smiths' do.	2	1	1						
Tinmans' do.	1	1							
Farriers' do.	2	—	—	1	1				
Coopers' do.	1	—	—	—	1				
Bricklayers' and Masons' do.	1	—	—	1					
Collar-makers' do.	1	—	—	1					
Axes, pick	50	10	10	10	10	10			
—— felling	18	3	—	3	3	9			
———— (Canadian)	24	6	6	6	6				
Barrows, hand	6	—	2	2	—	2			
Bars, crow, 5 ft.	4	2	2						
———— $4\frac{1}{4}$ ft.	4	—	2	—	—	2			
———— $2\frac{1}{4}$ ft.	4	2	—	—	—	2			
Bags, leather, for 60 lbs. powder	12	6	—	—	—	6			
—— sand	1000	200	200	200	200	200			
Billhooks	20	4	4	4	4	4			
Blocks and tackles	2	—	—	—	—	2			
Canvas, bolt	1	—	—	1					
Chokers, fascine, prs.	4	—	2	2					
Composition, waterproof, lbs.	15	3	3	3	3	3			
Grease, lbs.	10	2	2	2	2	2			
Handles, spare shovel	25	5	5	5	5	5			
Helves, spare pickaxe	25	5	5	5	5	5			
———— felling axe	12	2	—	2	2	6			
Ink bottles	4	—	—	—	—	4			
Jacks, iron screw lifting	2	—	—	1	1				
Knee caps	4	—	—	—	—	4			
Knives, gabion	10	—	5	5					
Ladders, scaling, 12 ft.	2	—	—	—	2				
———— 6 ft.	1	—	—	—	1				
Levels, field service	6	2	2	—	—	2			
Lines: Tracing, 50 yds.	3	—	—	—	—	3			
Lines: Hambro', in skeins	3	—	—	—	—	3			
Lines: Marline, white	3	—	—	—	—	3			
Lines: —— tarred	3	—	—	—	—	3			

DISTRIBUTION OF TOOLS, MATERIALS, &c.—*Continued.*

Description of Articles.	No. for each Company.	Waggons. 1	2	3	4	5	6	Forge Cart.	Remarks.
Locks, pad	12	—	—	—	—	12			
Mallets, beetle	2	1	—	1					
Pens, steel, boxes	4	—	—	—	—	4			
Pencils, lead	24	—	—	—	—	24			
Pickets, park	6	2	—	4					
Rope, tarred, 3-in coils	1	—	—	—	—	1			
———— $1\frac{1}{2}$-in. do.	1	—	1						
Rods, boning, sets	1	1							
—— measuring, 6 ft.	10	2	2	2	2	2			
———— 4 ft.	10	2	2	2	2	2			
———— 10 ft.	5	1	1	1	1	1			
Shovels, T-handles	50	10	10	10	10	10			
Spades	10	5	5						
Spun yarn, lbs.	30	—	—	30					
Steelyards, complete	1	1							
Tapes, measuring, 50 ft.	6	3	—	—	—	3			
——tracing, 50 yds.	12	6	—	6					
Tarpaulins, 7 yds. × 6 yds.	1	—	—	—	—	1			
———— 4 yds. × 3 yds.	1	—	—	—	—	1			
Mining tools, 1st box containing— 4 Jumpers, 7 ft. 1 Tamping bar, 7 ft. 1 Worm, 7 ft. 1 Needle, 7 ft. 1 Scoop or scraper, 7′ × 3″	1	—	1						
2nd box— 5 Jumpers, 7 ft. 1 Needle, 7 ft. 1 Scoop, 7′ × $3\frac{1}{2}$″	1	—	—	—	1				
3rd box— 9 Jumpers, 5′ 6″ 2 Crows, 4′ 6″ 2 ——— 3′ 6″ 1 Boring bar, 5′ 0″ 1 Worm, 4′ 0″ 2 Needles, 4′ 0″ 1 Scraper, 4′ × $1\frac{1}{2}$″ 1 Tamping bar, 4′ 0″	1	—	—	—	1				
4th box— 2 Crows, 2′ 6″ 1 Boring bar, 2′ 6″ 2 Sledge hammers 6 Striking do. 1 Powder-horn 2 Priming wires 9 9″ wedges 9 10″ do.	1	—	—	—	—	1			
Match, slow, lbs.	10	—	—	—	—	10			
Beckford's fuze dry soils, fms.	25	—	—	—	—	25			
———— damp do., fms.	25	—	—	—	—	25			
Portfires	36	—	—	—	—	36			
——— sticks	6	—	—	—	—	6			
Horse-shoes, sets	100	20	20	20	20	20			
Grindstone, 10-inch	2	—	1	—	—	1			
———— 18-inch	1	—	—	—	1				

C. R. B.

SOD-WORK.*—*Revetment of Sods.*—Sod-work forms a strong and durable revetment:† the sod should be cut from a well-clothed sward, with the grass of a fine short blade and thickly matted roots. If the grass is long, it should be mowed before the sod is cut.

Sods are of two sizes; one termed "stretchers," 12 inches square and 4½ inches thick; the others termed "headers," are 18 inches long, 12 broad, and 4½ thick.

The sod revetment is commenced as soon as the parapet is raised to the level of the tread of the banquette. A layer of sods is then placed either horizontally or inclined a little inwards‡ from the banquette: the layer consists of two stretchers and one header alternately, the end of the header laid to the front. The grass inside is laid downward, and the sods should protrude a little beyond the line of the interior slope, for the purpose of trimming the layer even before laying another, and to make the slope regular. The layer is firmly settled by tapping each sod as it is laid with a spade or a wooden mallet, and the earth of the parapet is packed closely beyond the layer.

A second layer is placed on the first, so as to cover the joints, or, as it is termed, to break joint with it; using otherwise the same precautions as in the first. The top layer is laid with the grass-side up, and in some cases pegs are driven through the sods of two layers, to connect the whole more firmly.

When cut from a wet soil, the sods should not be laid until they are partially dried; otherwise they will shrink, and the revetment will crack in drying. In hot weather the revetment should be watered frequently until the grass puts forth. The sods are cut rather larger than required for use, and are trimmed to a proper size.

G. G. L.

STAFF.—In the British Service the *Staff* of the Army is composed of the following Departments:

1. The Quarter-Master-General;
2. The Adjutant-General;
3. The Military Secretary.

These form component parts of the Horse Guards, London, the office of the General Commanding in chief, and through which departments of the army all business is transacted of which that high personage has the control, and which is limited to the *personel* of the army, *the finance* being a separate and independent branch under the Secretary at War, holding a seat in Parliament, and a Cabinet Minister, who, since the abolition of the Board of Ordnance, has charge also of the *matériel.*

The duties of the Quarter-Master-General embrace the disposition, movements, and quartering and embarkation and disembarkation of the troops.

Those of the Adjutant-General include the economy, discipline, recruiting, clothing, and general efficiency of the service.

The duties of the Military Secretary are the general correspondence with the Commander-in-Chief, and the appointment and promotion of the officers of the Army.

The peculiar constitution of the government of Her Majesty's Land Forces arises

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* From a Treatise on Field Fortification, by D. H. Mahan, Professor in the United States' Military Academy.

† For the interior slopes of parapets and profile walls.

‡ That is, perpendicular to the interior slope.

from the natural jealousy of a free State, where the people are averse to military government, and are willing to distribute the patronage and control among as many independent departments as possible, without absolutely impeding the working of the system. During peace, the several duties, comprising *Personel*, *Finance*, and *Matériel*, do not clash, and being under the control likewise of the Sovereign and a responsible government, the business of the army is carried on without difficulty. As adjuncts to the staff at the Horse Guards, are the Medical Department, the Chaplain General's Department, and Judge Advocate's Department, subject to the control of the Commander-in-Chief.

These departments are attached to the head-quarters of an army, or the divisions of an army in the field, in the colonies, and in the several military districts at home, each having a

Deputy or Assistant Quarter-master-General;
,, ,, Adjutant-General;
Military Secretary;
Senior Medical Officer:
Commissary General;
Commanding Officer of Artillery;
Commanding Engineer;

the four last being heads of departments, reporting likewise to the Chiefs of Departments in England; but the duties of the first are identical with those of the Horse Guards, with the addition to the Adjutant-General of the regulation of the supply of musket-ball ammunition, and to the Military Secretary of recording the expenditure authorised by the commander of the forces.

The officers of the Quarter-Master-General's department in the field have special duties entrusted to them, which the following order of the late General Sir George Murray, Quarter-Master-General, to his officers in the Peninsular war, will explain.

"The following points are to be particularly attended to by an officer of the Quarter-Master-General's department attached to a division of the army or to any other corps:

"He is to be at all times informed of the strength of the corps to which he is attached, what detachments have been made from it, on what service, and to what places.

"He is to be generally informed in regard to the supply of the troops with provisions and forage, to know whence the supplies are drawn, whether the issues are regular, and what means of conveyance are attached to the division or are within reach of being applied to its use either for commissariat purposes or for other services that may occur.

"He will attend to the division being kept complete in articles of camp equipage, intrenching tools, mules, and such other equipments for the field as are allowed, and he will collect and transmit to the Quarter-Master-General the returns which regiments are ordered to give in, monthly, of articles of field equipment, a form of which return is annexed (B).

"It is the duty of the Assistant Quarter-Master-General to allot the quarters of the division when it is cantoned, and to fix upon the ground which it is to occupy when it is encamped or hutted, or when the troops are to bivouac.

"When the whole division, or a considerable part of it, is to be quartered in the same town or village, it may save time to divide the houses into lots, and allow the several corps to draw for them (unless some particular distribution of the troops has

been ordered), making allowances afterwards for inequality of strength, as may be necessary.

"The allotment of the quarters of each corps in detail must be made by the regimental Quarter-Masters or other Officers sent forward by each with the Assistant Quarter-Master-General for that purpose; in like manner as it is their business to divide the ground, and mark out the streets, for their respective regiments, when the troops encamp.

"Regimental Officers must at all times take their quarters within the district of the town which is attached to their respective corps.

"The General Officers who command brigades should, if possible, be quartered also in the vicinity of the troops under their orders.

"The quarters of the General Staff attached to the division should be fixed with reference not to their rank alone, but more especially with a view to the convenience of those branches of the Service which they have to conduct, and to their being near the quarters of the General commanding the division.

"The guns and carriages of the Artillery should be parked in some open space where they are not in the way, and whence there is easy access to the road: an Officer of Artillery should be sent forward to assist in the arrangements for that branch of the Service, in like manner as an Officer should be sent from each regiment and department.

"The Commissariat Department should be placed in a situation where the carts and mules attached to it, or the making the issues to the troops, will occasion the least possible obstruction and embarrassment.

"A guard-room should be marked in the situation most convenient for the purpose, and alarm-posts should be assigned to the several corps; it will rest with the General Officers of the division to order whether or not the several regiments shall march to their alarm-posts on their first arrival at the cantonment, and be from thence distributed to their quarters.

"It is desirable that the Generals should each send forward an Officer of their personal staff to mark their quarters, as it must frequently happen that the Assistant Quarter-Master-General is prevented by his other duties from making the best selection for them that the place affords.

"It will depend upon circumstances whether or not the Assistant Quarter-Master-General can precede the march (which on all ordinary occasions, however, he ought to do) long enough to enable him to complete all the arrangements above mentioned before the arrival of the troops.

"The Assistant Quarter-Master-General should lose no time in making himself acquainted with the country in the neighbourhood of the cantonments, and he should make, at the same time, a tracing or sketch of it, showing the situation of the several villages, the roads by which they communicate, the rivulets, &c.

"He will receive the orders of the General Officer commanding the division in regard to placing the outposts or picquets that are deemed necessary, the instructions to be given to each, and the connection to be established with the outposts of any other corps.

"When two or more divisions are to take up their quarters in the same town, or are to encamp together, the several Officers of the Quarter-Master-General's department who are attached to them will make their arrangements in concert, as may be best for the Service in general. The senior Assistant will be responsible, however, that no improper interference and no delay in providing for the accommodation of the troops take place.

"When a division marches, it will be the business of the Assistant Quarter-Master-

General (if not previously sent forward) to see the column formed, and to take care that the several corps, the artillery, the baggage, &c., are all in their proper places, and that there are no unnecessary intervals during the march: he will be with the advanced guard (if not otherwise ordered); he will cause all obstacles that would interrupt or delay the march of the troops to be moved out of the road, and will order such temporary repairs as are necessary, and as can be effected by the pioneers at the head of the column.

"In most ordinary cases, however, the repairs of roads, bridges, &c., requisite to facilitate the march of troops should be done by the people of the country, upon an order to the magistrates from the General or other Officer commanding in the neighbourhood, for that purpose.

"When the division is to encamp, it is the business of the Assistant Quarter-Master-General to point out the ground to be occupied, and show how it is to be taken up: he will ascertain and point out how the troops can enter the camp with the greatest ease, where wood and water are to be found, and what communications must be opened either between the several corps of the division itself, or to enable it to communicate with other divisions on either flank in front or in rear.

"On ordinary marches, it will in general be unnecessary to take up as a military position the ground to be occupied, and it will be better to place the troops in such a manner as will be most convenient for wood and water, for shelter, and for moving into the road again on the next march: the troops will, by such attentions, be saved from a great deal of unnecessary fatigue, in which view also they must never be kept waiting for their quarters or their ground of encampment at the end of a march, as all arrangements that depend upon the Officers of the Quarter-Master-General's department ought (except in extraordinary cases) to be completed before the troops arrive.

"An Assistant Quarter-Master-General employed with a division of the army ought to have an interpreter, and he will be allowed to charge his pay in his contingent accounts, having previously reported the rate of pay to the Quarter-Master-General, and obtained his sanction for it.

"He must be constantly provided with guides also, when the division is in the field, and more especially if it is moving or acting separately from the body of the army, so that in the event of any sudden movement of the whole division, or of any detachment from it, either during the day or night, guides may be always at hand: such should be selected, if possible, as are not only capable of showing the road from one place to another, but as are also men of intelligence, and who have a general acquaintance with the neighbouring country: these guides ought to be obtained through the magistrates of the country; when permanently attached, they should have a fixed pay per diem, but when employed for a temporary purpose, they should be paid in proportion to the distance they travel, or the nature of the service they are employed upon, or other circumstances, and according to their being mounted or on foot; all guides who are detained for a day or more should have rations drawn for them: guides taken from village to village on ordinary marches need not be paid.

"The other charges which the Officers of the Department are allowed to make against the public are specified in the instructions respecting the mode of making out their contingent accounts. When Officers of the Department have occasion to issue routes for the march of troops or convoys, or to individuals, they are to be made out according to form: an entry is to be made of all routes, and copies are always to be transmitted at the time of their being issued, or as soon after as possible, to the Quarter-Master-General, and likewise to the Officer commanding at the station to

which the corps, the convoy, or individuals are proceeding. It will be sometimes necessary to report the march also to some intermediate stations through which troops are to pass, especially if their number is considerable, in order that preparation may be made accordingly.

(Signed) "GEO. MURRAY, Q. M. G."

"*Cartaxo, Dec. 2nd,* 1810."

Return of Field Equipment for Cavalry Regiments. B.

	Camp Equipage.															Intrenching tools.				Pack-saddles and mules							
						a	a	a	a	a	a	a	a	a	a									a	a		
	Tents.	Canteens and straps.	Haversacks.	Bill-hooks.	Camp-kettles.	Picket-posts.	Great Mallets.	Breast lines.	Water buckets.	Forge cords.	Hair nose-bags.	Corn sacks.	Reaping-hooks.	Water-decks.	Blankets.	Spades.	Shovels.	Pickaxes.	Felling axes.	Pack-saddles.	Bridles and collars.	Medicine panniers.	Baggage straps.	Armourers' panniers.	Sadlers' panniers.	Public mules.	Reaping-hooks.
Received since last return .																											
Serviceable .																											
Unserviceable																											
Wanting . .																											

N.B.—The return for Infantry Regiments is the same, omitting the columns marked (*a*)

The especial Duties of the Commissariat.—When in the field, this department has the custody of the military chest, the supply of everything necessary for the provisionment and forage of the army, and of advances to the several departments,—the supply of money, the transport of the troops, and the establishment of dépôts and magazines for furnishing the several wants. In the Colonies, the Commissariat has the charge of the military chests, the negociation of bills to keep up the supply of money, and it makes advances to Paymasters for the troops, and to the Heads of Departments for their disbursements: it contracts for provisions for the troops, and issues the same in detail, as likewise it purchases all articles obtained in the colony or foreign possession. This Department is under the orders of and is responsible to the General or Officer commanding for the execution of its duties at the various stations abroad. But the Commissariat is also responsible to the Treasury for all its acts, to whom it reports on all points of service, and the Officers of the department are dependent on the Treasury for promotion and appointment, and the organisation proceeds and emanates from the Treasury. At Home, the services of the Commissariat are little required, beyond giving assistance in the administration of the Treasury branch of that department, and auditing the accounts.

The duties of the Officers commanding the Artillery and Engineers at head-quarters forming part of the Staff of the Army, are to convey instructions of a departmental nature to the several detachments of those corps, and to afford information to the General commanding upon all points connected with their duties. These duties are explained under the articles 'Engineer' and 'Equipment.'

The Senior Medical Officer in a similar manner affords information to the General commanding of the sick and wants of his department, establishes dépôts for the sick and wounded, and controls and secures the officering of the whole medical department.

In Foreign Service, the Military Staff is under one head, the Chef d'Etat Major, and the Etat Major is mostly educated expressly for its respective duties. Besides Woolwich for the Artillery and Engineers, we have now a Staff College for the Staff of the Army, and the appointments for the Quarter-Master-General, Adjutant-General, and Military Secretaries, as well as personal Staff of General Officers, are directed to be generally filled from that source.

The object of this short sketch is to give the composition of the Staff of the British Army, rather than an explanation of its duties, which can only be acquired in the field. On actual service, activity and intelligence are the chief essentials, and a General commanding either a division, a corps, or an army, can never move a force successfully and without confusion, unless he has intelligent Officers on the Staff to direct the movements, and who possess also a perfect knowledge of the country.

The General himself must remain near his troops, but the Staff will have previously learnt the nature of the country, and guide and provide for their movement in all unforeseen difficulties.—G. G. L.

STATISTICS.*—The statistics of a subject on the facts connected with that subject, and the art or science of statistics, consist in so arranging those facts as to exhibit them in the clearest light, to show their connection with or dependence on each other, and so grouping them in heads, or sub-heads, as to reduce the leading principles to as small a number as possible. Thus in Natural History we have orders, classes, genera, species, and varieties, several of each lower denomination being contained in the one next above it. The same may be said of every other science. The observations, and the clear record of those observations, form the first process of the Statistician, while the laws to be deduced from them, and the application of those laws to individual or special use, are the rich reward of his labours.

It is needless to say that the value of observations depends chiefly on their accuracy, and the degree of intelligence as well as care with which they are collected, lest by the omission of some peculiar phenomenon, easily observed at the time, the value of the series or collection be impaired; and from this it will be seen that the statistical observer ought to possess a certain degree of knowledge of the science for which his collections are made. It is not indeed absolutely indispensable that the collector of vital statistics should be a Physician; nor that the collector of the statistics of trade and exchange should be versed in Political Economy; but there can be no doubt that his observations will be more useful, and his labours will be of a higher order, if he be conversant with their object and with the uses which will afterwards be made of them; and not only the immediate object, but objects connected or cognate with it, because so intimately blended are the numerous sciences, that none can be exhausted without contact with others.

Individual exertion, however, is, generally speaking, so much more profitable when confined to one pursuit, that it is frequently sought to combine this advantage with the advantages of extended inquiry, by centralising the observations of numerous collectors on a general and uniform system, rather than by the labour of one observer

* By Major-General Sir Thomas Larcom, R.E.

on many subjects. This is accomplished by the circulation of queries and forms, the answers to which are afterwards to be generalised and combined in one place, and this is the more necessary the more extensive the subject, particularly when new or recondite in its nature. In this manner our brother Officers, as a body, may be most useful whenever it may be thought desirable to circulate such for any particular purpose. Of this we have a distinguished example, in the magnetic and meteorological observations which for some years past have been simultaneously carried on at numerous stations carefully selected all over the world, the British Colonial portion of which has been executed under a distinguished officer, Colonel Sabine, of the highest scientific attainments, by Officers of the Royal Artillery,* acting on instructions and forms previously prepared. No subject is at first more variable and more subject to disturbing causes, many of which were indeed unknown, yet we have begun already to see the results of this combined exertion, in which the British observations have borne so prominent a part, and already the multiplied facts have grouped themselves around laws which will shortly bring their object within the domain of the exact sciences. But numerous as the stations are at which observations have been made or are in progress, they are still far short of the number of our Colonies, and there is not one in which such observations would not be useful. Instruments are now to be had at moderate prices, with full and clear instructions for their use. The relative mortality of colonies has also been the subject of extensive inquiry, by the Medical Officers of the Army and Navy, with great credit to themselves and benefit to the country. In the article on Geognosy and Geology, in the second volume, Maj.-Gen. Portlock has pointed our attention to a subject of great practical as well as scientific importance, in which our combined exertions may advance a common end—a subject on which that Officer speaks from experience, as well as with the authority of extensive knowledge of the subject; and there is none perhaps of greater utilitarian scope, nor which, with its cognate branches of Natural History, will more amply reward the inquirer, by opening new objects of contemplation and interest at every step. These noble sciences have themselves indeed long passed beyond the category of statistical inquiry, but they may be aided by it, and they lead to those of an industrial and social order, in which the field is comparatively untrod, and in which the labours of the statist are eminently required. The value of a colony to a commercial country depends either on its productions, or its naval and military position in regard to more productive districts, for which it may form an entrepôt, a place d'armes, a halting-place, or coaling dépôt. An exact knowledge of those productions, or of those circumstances, and of the changes which take place, or which may be made in them, becomes of the highest importance.

The first general consideration in regard to a Colony would be its natural condition, or that in which it has passed from the hands of its Maker, and here we have exact sciences to aid us,—its position on the earth's surface in latitude and longitude, and its interior topographical delineation, now rendered easy to us from the number of officers and soldiers of the Corps who have been trained on the Survey. The Geologist and the Naturalist follow, and these are the preliminary investigations, on which all subsequent inquiries can best be based. Without them we should be in danger of proceeding on an useless quest: with their aid, and the light they afford, we shall easily discern the object which the colony is most fitted to fulfil, and our statistical inquiries will be directed to the best means of forwarding that object. The resources of the country will perhaps be of a mineral nature, or they may be commercial, or agricultural, or its advantages may be of a purely military nature.

* Latterly by Officers of Royal Engineers.—Ed.

The "physical means" by which these may be facilitated should next be considered,—those which the Government may be expected to perform or assist, as public defences, buildings, lighthouses, roads, or harbours, and those which may safely be confided to individual enterprise, as machinery, or the more immediate means of industry; next, the class of labour most likely to be useful; and here the subject of colonisation and convict labour, now prominent in the public mind, may be largely aided by our observations. It would be idle to send the colliers of Newcastle or Carlisle to the pastures of Sydney, or the Agricultural population of the South Downs to the coal-pits of Cape Breton. The price of the several descriptions of labour, and of the commodity produced by it, at the present and in former times, is the best guide to the class of inquiries which deals with the labour-market. The extent to which raw produce of every kind can be advanced in the various steps of manufacture through which they pass, before they are fitted for the use of man, should be carefully observed. To a certain extent this operation can be performed with advantage on the spot; beyond that extent it will, generally speaking, be more profitable to export or exchange the commodity. On all these points price is the certain guide, and no economical inquiry, whether of production or manufacture, can be complete without it.

The social position of a colony involves other considerations, and requires a different class of inquiry. The first subject would probably be an account of the population, British and native. Security and protection are the next and indispensable elements, without which organised society cannot subsist. In a colony these usually depend upon the mother country, aided financially by the colony, and they are more or less alike in all. Next in order is the administration of justice and law, and the degree in which the native customs or courts are employed. Education in all its branches should be the subject of careful examination, as well of the native as of the British population, and industrial or agricultural education as well as literary or intellectual. The religious institutions and establishments may be the bond of society and the fountain of truth and peace, or the source of heart-burning and discord. Immediately connected with these will be the institutions of a benevolent order. They address themselves to the relief of physical suffering, whether in the form of disease or indigence, as those of religion and education do to the moral and mental wants of the community. The hospitals, the manner in which they are supported, the number of patients, the relative and absolute prevalence and extent of the various diseases, may easily be observed or obtained. These form the principal heads of this branch, while to the sufferings of poverty there are generally also modes of alleviation which should be recorded in connection with the social state of the people.

It would be impossible briefly to describe the numberless subjects of inquiry which come within the range of statistic research, nor can it be supposed that every one will be able or be disposed, even if time and opportunity permitted, to enter upon all of them. But there are few Officers who will not find interest in one or more. Having chosen his subject, he would find no difficulty in procuring examples and instructions, and in the Editors of the 'Corps Papers' is certain to have brother Officers able and willing to counsel or direct him, and present the results of his labours in an uniform and digested state.

The social and industrial condition may, however, be considered the branches of the subject which most naturally devolve on the statistical inquirer, being the most readily expressed in numbers, though few will be found to dissent from the more general application of the term which has been given in the commencement of this article, more especially in reference to the pursuits and means of information

of the class of Officers for whom these volumes are compiled. Regarding, for example, the ultimate collection of colonial memoirs as an object worthy of the 'Professional Papers,' or similar military works, Officers who feel difficulty in entering upon all the branches of so comprehensive a subject, and yet find every branch dependent upon the others, and all to some extent resting upon the first points, above adverted to, viz. the natural condition, as divided into geography and natural history, and influenced by the objects and destination of the colony, may leave these heads, which are elsewhere treated of, and enter upon the more numerical subjects, perhaps in somewhat the following order.

1. Population.

1. *Population,*—of which an authentic census is generally taken periodically; but this will be very imperfect if merely confined, as used formerly to be the case, to enumeration only. As much as a disciplined army of small numbers is superior to a rabble of fifty times its amount, so is a well-ordered community to one in the reverse condition; and as a general rule, to which of course there are exceptions, we may usually, when we hear of a country being over-peopled, assume that it is in reality only ill-organised or mismanaged. If such were not the case, the density of population would be the best possible measure of the security, wealth, and industry of a country; and, however dense the population, the country would not be over-peopled. The degree in which it is so is, therefore, a measure of its weakness; but we must take a sufficiently large view of the word *country*, and not limit it to a mere district. We must also look to the circumstances and condition of the people, not merely to their numbers. The clue to these circumstances may generally be found in a skilfully conducted census, or in carefully sifting and digesting it afterwards.

A few leading proportions may easily be borne in mind, and they are convenient as comparative tests. The number of male and female births are usually as 106 to 100. In the first month one-tenth will die. At 5 years of age, more than a third are gone; at 10 years of age, more than half. The male deaths will preponderate in early life, so that at the age of from 14 to 15 or 16 the numbers of the sexes will have become equal. This is also the age above and below which the gross numbers will be nearly equal to each other, in a population increasing in an arithmetical progression of 1·3 annually. The soundest condition of a population is that in which the greater number are maintained in the working age, while a population which has a large proportion of its numbers at ages either so young or so old as to require maintenance or support, instead of contributing to it, is obviously a source of weakness to the state.

It is therefore necessary, in any enumeration of a people, to divide them into ages, distinguishing the single years up to 5, then passing to 10, and continuing in tens upwards. The number of persons divided by the number of families gives generally about 5 to a family,—and that number ought also to be the number to a house. But the words *family* and *house* require definition: the former should be understood to mean one or more persons living on their own means of support, and may, in a large average, include servants. The latter is, strictly speaking, the accommodation occupied by that party—not one set of walls and roof. "House accommodation" is therefore a better designation than House; and the important matter to investigate in this respect is the extent of such accommodation which every family enjoys divided into as many classes as may be found convenient or suitable to the country and climate. Houses may be classified according to the number of windows, as indicating the number of rooms (*i. e.* magnitude), the quality of the walls and roof, with any other circumstances which measure size and quality in a particular country. The house may then be placed in a first, second, or third class, in regard to each of these conditions, and ultimately in its general class as resulting from the component classes.

Having thus classed the houses, it is necessary to know the number of families living in each, and to resolve what accommodation each family enjoys, compared to the accommodation of single houses of smaller dimension. Five or six families, for example, in a first-class house would be as ill-accommodated as if all were in third or fourth class houses, and so on.

It is also of importance to observe the occupations of the people. It has been usual to make two great classes—agricultural and manufacturing. This broad distinction has been adopted in our own country, and has its utility as marking the transition of a community from the one to the other state with advancing knowledge and wealth. But it is obvious that after a time the distinction is more apparent than real, and is not based on any philosophical view, as agriculture is itself a manufacturing process. A sounder distinction is into primary and secondary manufacture, according as we deal with a first production of raw material, or the advances of the material by a second or third process. In a colonial population this would become more apparent, and the occupations of the community would in many cases be neither the one nor the other, in their strict sense, but combining both; as it would be difficult to separate, for example, the boiling of sugar on a sugar establishment from the growth of the cane, which is clearly agricultural, on the one hand; or, on the other, from the ultimate refining, which is afterwards carried on in England, and is as clearly manufacturing. These great divisions at home have grown out of the destination of the country to supply subsistence, food, and clothing to the inhabitants in return for their labour. The destination and object of a colony will furnish, in like manner, a guide to the best classification for the occupation of its inhabitants.

2. Laws.

2. From the population we may pass to the constitution of the laws which govern it and afford protection and security. These in regard to a colony are of two kinds: First, from external aggression by the garrison and means of defence supplied wholly or in part from the mother country; but frequently aided by the colony at least in expense. The strength of the garrison during war and during peace, and the nava force, if any, form the chief subjects; and a succinct account of any occasion on which their sufficiency has been tested. Second, from internal confusion either by military rule, or by the local government of a legislative or executive assembly, and by the administration of law—whether British, native, or foreign. The statistics of crime here naturally occur, which it is usual to divide into two heads, as committed against person or against property. Returns of these may generally be collected or procured, and they should always be connected with the age at which committed, and the extent of education of the criminal, with circumstances of season and climate. It is known that the tendency to crime is greatest at about twenty-five years of age, and it has been supposed that as education extends, the crimes against property predominate over those against the person. But if education be confined to the lower elements of its merely intellectual branch, it is probable all classes of crime will rather increase than diminish.* We only furnish the criminal with better weapons and better means. The crimes against property will be greatest where the greatest irregularity of property prevails. Climate and seasons also influence the extent and class of crime materially. So far as European inquiry has extended, crimes of violence are most abundant in the south, and those against property in the north. The seasons are somewhat similar in their effects. Age and sex also influence crime. The greater strength of the male leads to violence, the reverse leads females to poisoning or fraud. Age is of all causes the most influential. Crime increases with age till the strength of the body is complete, but does not decay as rapidly, though its

* The evil influence of education, without Christianity, was painfully and fearfully shown by the Nana of Bithoor and others in the late Indian Mutiny.—Ed.

direction changes from violence to fraud. But Man is influenced by the moral physical circumstances in which he is placed as much as by his organisation, and the former are largely within our own control. Crime is a measure of the care and development they have received and are receiving.

3. Education. 3. Education, in its three divisions, religious, intellectual, and industrial, is a subject to which all enlightened minds devote themselves with eagerness, and the extent to which it prevails, or the facility of obtaining it, in any community, is always to be sought for. Numbers may be easily given in tabular forms, and the funds by which schools are supported; but the class of instruction is yet more important. The books which are read, and the class of persons by whom the instruction is afforded, with the manner of affording it, are more important: nor should education be considered as ceasing with childhood; to be effectual, it must continue to the very close of life, varying only in its nature and object. Public and private libraries, scientific and literary institutions, come all within the category of education, and more than all the religious and moral instruction not only of children but of the adult community. In regard to children, the number between the ages of 5 and 15 is usually about a quarter of the whole community, and at least half that number ought to be at school at any given time at which an enumeration is made. That proportion would still be small, but it would afford hopes that during the whole 10 years every child may have passed half its time at school.

4. Institutions. 4. Benevolent institutions also challenge our attention: they address themselves to the relief of inevitable suffering, whether from sickness or poverty. The most palpable are hospitals, houses of refuge, or similar institutions, but benevolence exerts itself in a thousand forms, not less valuable because unobtrusive; and the extent to which it prevails in any community, the proportion in which it is fostered or supported by the Government, by endowment, or by private means, may generally be ascertained: the amount of funds devoted to these purposes, whether by endowment, by the aid of Government, or by private contributions; these and the number of persons relieved should form the subject of inquiry in each case. Medical statistics will enter into this category, and an Officer will be well employed in his leisure hours if he co-operate with any Medical Officer who is pursuing this subject. The provision for the poor and helpless comes of course into this category, and there is scarcely any country in which this is wholly disregarded, even when not made a public measure or under state control. The Officer who engages in this inquiry, will find his own benevolence awakened, and will be morally benefited by his exertions on the part of others.

5. Condition. 5. The industrial condition of a country, district, or colony, will of course depend, in the first instance, on its natural—modified, assisted, or retarded, by its social—condition. It may be indicated externally by its commerce with the mother country, or neighbouring countries, and internally by the material prosperity of its inhabitants. Of the former, the imports and exports, and places to and from which they are conveyed,—of the latter, wages and prices, are the truest indications. Local weights and measures, and their difference from the standards of Great Britain, as well as the monetary arrangements and local currency, are also to be noticed. In regard to land, the tenure, the manner in which rent is paid, whether in proportion to the produce, as one-third, one-fifth, or more or less, or by a fixed sum of money; and whether hereditary, quasi-hereditary, or continuous tenure, or mere tenure at will, be most prevalent;—the division of the land, the mode and class of cultivation, and the relative productions of different crops, and the manures used or required;—the implements of husbandry, the breeds of cattle, the introduction of peculiar grains or roots, and the country from which they were first brought;—the size of farms, and class

and amount of produce grown on each class. In regard to commerce, its nature and object; by what steps or parties carried on; how far beneficial to the producers of the commodity, the intermediate trader, the colony, or the mother country, —always remembering that wealth, whether in an individual or a country, is the possession of that which others want, and security for that possession or its exchange.

Moral condition and climate.

6. In the individual, moral rectitude and honesty, ability, industry, intellectual and physical strength, are the sources of wealth,—in the community, the advantages of nature in climate, soil, and geographical position, with the aid of social institutions affording full development of those resources.

It has not been sought to encumber this brief abstract with printed forms of queries or Tables, which rather encumber than assist. The means by which alone inquiries can be successfully conducted by single individuals, are reflection and study on the part of the individuals who conduct them; and mechanical substitutes, however useful when applied to a limited space or particular object, and circulated for that purpose, are, when applied generally, in danger of attaining only a dull uniformity at the cost of diminishing original thought. Few men who think long and clearly on any subject, will be at a loss for the most appropriate vehicle or form in which to embody the results of these labours.—T. A. L.

STEAM ENGINE.*

SECTION I.—MECHANICAL ACTION PRODUCED BY STEAM.

1. The instrument by which steam accomplishes this is almost invariably a piston, moveable in a cylinder.

A cylinder is a tube or pipe, but much larger in its diameter, in proportion to its length, than tubes or pipes usually are. Thus a common proportion for a cylinder is three feet in diameter, inside measure, and four feet or four and a half feet in length; but this proportion is very variable according to circumstances.

2. The piston is in effect a solid plug, fitting the interior of the cylinder with sufficient precision to prevent steam from passing from the one side to the other, but with sufficient freedom of motion to enable it to move along the cylinder without any considerable loss of force to keep it in motion.

3. The ends of the cylinder are understood to be closely stopped by lids. One of these lids is sometimes cast with the cylinder, and forms, in fact, part of it; the other is attached to it by screws and nuts, and fitted so exactly that steam cannot escape at the joints.

4. Small apertures are provided at each end of the cylinder, furnished with stoppers or valves, by which steam may be admitted or allowed to escape at pleasure.

5. Now it will be easily understood, that if a blast of steam be admitted at one end of the cylinder, it will blow the piston to the other end; if a blast of steam be admitted at the other end, that which had previously been admitted being allowed to escape, the piston will be blown back again.

If we have the means, then, of taking in a blast of steam alternately at the one end and at the other end of the cylinder, the piston will be blown constantly backwards and forwards from end to end.

The force with which this will be effected will depend on the force of the steam.

6. This alternate motion of the piston from end to end of the cylinder, made with

* By the late Dr. Lardner. Revised and corrected by E. Woods, Esq., C.E.

a certain degree of force, could accomplish nothing useful if it were confined within the cylinder; it must be communicated to something outside which is required to be set in motion.

7. This is accomplished by an appendage to one side of the piston, called the *piston-rod.* This is a round rod, firmly fixed into the centre of the piston, and passing through a hole made in the centre of the cover or lid of the cylinder, which I have already described, to be attached by screws and nuts. It must move in this hole as the piston does in the cylinder, so tightly as not to let any steam escape, and yet so freely as not to require any considerable power to urge it.

8. It will be easily understood, that to attain this object very great precision of form is necessary in the internal surface of the cylinder and in the piston-rod. The cylinder is made of cast iron, but the inner surface of it, after being cast, is reduced to a precise cylindrical form by a boring machine. This machine scrapes off all roughness, and reduces every part of the inner surface to an exact circular form, of precisely the same diameter throughout the entire length of the cylinder.

9. The piston, which is flat on either surface and circular at its edge, to correspond with the cylinder, is made to fit the cylinder in steam-tight contact, and at the same time to move freely in it by a variety of contrivances which will be noticed hereafter. For the present it will be sufficient to assume that mechanical art, in its present state, enables us to construct pistons and cylinders with so great a degree of precision that no steam whatever shall pass between them, and yet that the motion shall be almost perfectly free.

10. The piston-rod, also of iron, is turned in a lathe so as to be truly round, and uniformly of the same diameter throughout its length. The hole through which it plays in the top of the cylinder is surrounded by elastic packing, which presses against the sides of the piston-rod: and in this way, whilst the motion is free, no steam escapes.

11. The piston-rod thus partakes of the alternate motion which the piston itself receives, and conveys this motion to any object outside with which it may be connected.

12. Thus the primary motion produced by steam power is an alternate motion backwards and forwards in a straight line; but by an infinite variety of well-known mechanical contrivances, this alternate motion may be made to produce any other kind of motion that may be desired; thus we may make it keep a wheel in constant rotation, or move a weight continually in the same straight line and in the same direction.

13. These points will be hereafter explained; for the present we establish the fact that steam can by the means indicated produce an alternate force backwards and forwards along a cylinder with a degree of energy proportionate to the force of the steam, and with a degree of speed proportionate to the rate at which the steam can be supplied.

SECTION II.—THE PROPERTIES OF STEAM.

1. I have spoken of the piston in the cylinder being driven from one end to the other by a *blast* of steam. This will at once suggest the resemblance of steam to air. Steam possesses, in fact, a set of properties precisely the same as air: if air were heated to the same temperature as steam, it would, to all intents and purposes, possess the same mechanical properties: and if it were as manageable in other respects as steam is, we should have no occasion to resort to steam engines, but should have nothing but air engines. Air could blow the piston from end to end of the cylinder as well and in exactly the same manner as steam does. It will therefore

greatly facilitate the comprehension of the qualities of steam to attend, in the first instance, to the corresponding qualities of air.

2. Air is an elastic fluid,—so is steam.

The meaning of an elastic fluid is one which may be squeezed or compressed into a less bulk; or, on the other hand, which will expand itself into a greater bulk spontaneously if room be given to it.

3. All fluids, however, do not enjoy this property: water does not partake of it at all; it cannot be squeezed by any practical force into less dimensions than it naturally occupies, and whatever room you may give to it, it will not expand into greater volume. If air be enclosed in any vessel, it will spontaneously press on every part of the inner surface of such vessel with a certain force, tending, as it were, to burst the vessel. This is what is called its *elasticity*. If it be squeezed into a vessel of half the size, it will press on the inner surface of this vessel with just double the force; and if, on the other hand, it be allowed a vessel of twice the size, it will spontaneously expand and fill every part of such vessel, but will press on it with a diminished force, amounting to one-half its original pressure.

4. In short, you may by compression reduce its bulk in any required proportion, and its bursting or elastic force will be augmented in exactly the same proportion; and you may, on the other hand, permit it to expand to any augmented volume, and its pressure will be diminished in precisely the proportion in which its volume will be increased.

5. All these are equally qualities of steam.

Air is an invisible fluid,—so is steam. It is a great mistake to imagine that the cloudy vapour that is seen issuing like white smoke from steam vessels or boilers is steam; the moment it becomes thus white and cloudy it ceases to be pure steam.

These misty particles are particles or vesicles of water, and not pure steam. If a glass vessel were filled with pure steam, it would be as invisible as when filled with air.

6. Steam is a species of air made from water.

Air may exist in different states of density, so may steam. In either case the pressure or elasticity (other circumstances being the same) is in proportion to the density.

7. But as air is everywhere accessible and disposable, it may be asked why we may not use it for those mechanical purposes for which steam has proved so omnipotent, especially seeing that the production of one is attended with great cost and trouble, while the other exists in unbounded quantity, and can be had everywhere and for nothing. To answer this we must consider those qualities in which steam differs from air.

SECTION III.—HOW WATER IS CONVERTED INTO STEAM, AND HOW STEAM IS RECONVERTED INTO WATER.

1. If any source of heat be applied to water, the first and obvious effect will be to render the water hotter.

2. But to this there will speedily be a limit. It will be found that when water under any given constant pressure has attained a certain temperature, no further application of heat will augment its temperature, but it will then begin to diminish in quantity, and, as it were, to disappear; and if the application of heat be continued, the water will at length altogether vanish. It has in this case been gradually converted into steam, which has ascended into the surrounding atmosphere and mingled with it.

3. But this escape of the steam may be prevented. Let a second vessel be pro-

vided and put in connection with that in which the water is heated, and let the communication with the external air be cut off.

4. The steam produced from the water may be collected in this vessel, and when so collected, and submitted to examination, it will be found, as I have stated, to possess all the mechanical properties of air.

It thus appears that the liquid water is converted into the elastic fluid steam by a certain quantity of heat having been imparted to it.

5. One of the most remarkable changes which the water undergoes when it passes into the form of steam is its change of bulk, which is quite enormous.

6. It is found that a quart of water evaporated under ordinary circumstances will produce about 1700 quarts of steam; but this proportion varies with circumstances, as we shall now see.

7. Let us suppose that a piston is inserted in a tube, and that under the piston a small quantity of water is placed. For simplicity, let us suppose that quantity of water to be a cubic inch. Let the piston be arranged to press upon the water with a force of 15 lbs., the magnitude of the surface of the piston in contact with the water being a square inch; and let us in this case put out of consideration any effect of the pressure of the external atmosphere, this pressure being represented by the 15 lbs. imputed to the piston. Let a lamp be supposed to be applied under the tube, so as to heat the water within. The effect of the lamp for some time will be merely that of elevating the temperature of the water, but when the temperature shall have attained to 212° of Fahrenheit's thermometer, then the piston will be observed to begin to ascend in the cylinder, leaving an apparently unoccupied space between it and the water. The quantity of water will at the same time apparently diminish. The lamp continuing to act, the piston will continue slowly to ascend, and the water slowly to diminish, until at length all the water shall have disappeared.

8. The piston will then be found to have ascended to such a height that the space below it in the cylinder will be 1700 times greater than that which the water originally occupied. This space, which, if seen, as it might be, through glass, would appear empty, would in fact be filled with the steam produced from the water, which, like air, would be invisible.

9. In this case we have supposed the steam to be produced under a pressure of 15 lbs. on the square inch. Let us now, however, suppose things restored to their original state, and the piston to be loaded with 30 lbs., or with 15 lbs. in addition to the atmospheric pressure, which makes a total of 30 lbs. If the same process as before be repeated, it will now be found that before the piston begins to ascend, the temperature of the water will rise, not to 212°, as before, but to 252°; the piston will then begin, as before, to ascend, and will continue to ascend until all the water shall have disappeared. It will not, however, rise now so as to leave 1700 times the original bulk of the water below it, but only the half of that amount, leaving a space for the steam, thus produced, about 850 times greater than the bulk of the water.

In short, the piston may be loaded with any pressure greater or less than that which we have supposed. If loaded with a less pressure, the water will expand into steam of greater volume; and if loaded with a greater pressure, it will expand into steam of less volume. The temperature also at which the water will begin to be converted into steam will vary, being higher for greater pressure and lower for less pressure.

10. When the pressure is doubled, the steam produced will not be of precisely double the density, but will not vary much from that proportion. The reason of the

variation—small as it is—is, that when the pressure is doubled, the temperature of the steam is augmented, and an increase of volume due to such increase of temperature causes the density of the steam which results to be a little less than double the original density. This variation, however, is not considerable, and we may assume, as a simple approximate rule, that the density of steam is in the direct proportion of its pressure.

11. As it is of great advantage to retain in the memory the extent to which the volume of water is expanded when it is converted into steam, the following accidental proportion will be found useful: a cubic foot contains 1728 cubic inches. Now we shall be sufficiently near the truth, for all practical purposes, if we state that a cubic inch of water evaporated under a pressure of 15 lbs. per square inch will produce a cubic foot of steam. This statement is at once so simple and so striking, that it cannot be forgotten.

12. Knowing the volume of steam produced by a given quantity of water under this pressure, the volumes which will be produced under other pressures, greater or less, may be inferred with sufficient practical accuracy by the proportion already given. Under double the pressure, the volume would be one-half; and under half the pressure, the volume would be double. Thus, if water be boiled under a pressure of 30 lbs. per square inch, a cubic inch of water will produce half a cubic foot of steam; if it be boiled under 45 lbs. per square inch, it will produce one-third of a cubic foot of steam; and in like manner, if it be boiled under $7\frac{1}{2}$ lbs. per square inch, it will produce two cubic feet of steam; and under 5 lbs. per square inch, three cubic feet of steam, and so on.

13. This proportion would be strictly accurate but for the fact that the temperatures at which the water boils in these cases are different; but the difference due to this need not be now attended to.

14. It may also be observed, that in general, when the water boiled is exposed to the atmosphere, the atmosphere itself produces an average pressure of 15 lbs. per square inch, which is understood to be included in the above pressures.

15. Having thus described the manner in which water is converted into steam, let us now see how steam is converted into water.

The steam which is produced from the water in the manner we have described has the same temperature as the water from whence it proceeds. This temperature is indispensable to it. The moment you deprive it of any heat, that moment a portion of it returns to the state of water, and by the continued abstraction of heat from it, it will all return to the liquid state.

16. Let us suppose, in the tube which we have already used for our illustration, that after the piston has ascended, and the water has been all converted into steam, the tube be surrounded by any cold medium, such as a cold atmosphere, the lamp being in the meanwhile withdrawn; immediately a dew will be formed on the inner surface of the tube, and the piston will begin to descend. The dew thus formed is the water reproduced from the steam, which has been restored to its liquid state, in small particles: these are swept down before the piston, and at length, when the piston shall have arrived at its original position, all the water will have re-appeared at the bottom of the tube.

The steam will, in fact, have been reconverted into water.

17. Thus, as heat is the agent by which water is converted into steam, the abstraction of heat is the means by which steam is reconverted into water.

This is one of the most important qualities in which steam differs from air. No known degree of cold is capable of converting air into a liquid, although analogy justifies the inference that some degree of cold, though unattainable by any means yet

known, would effect this. There are some airs, in fact, on which art has produced this effect, but it has never been accomplished on the atmosphere.

18. It is precisely this quality, giving us the power of reconverting steam into water at pleasure, which enables us to use steam so extensively for mechanical purposes, and deprives air of the same mechanical utility.

SECTION IV.—THE MECHANICAL EFFECT PRODUCED BY THE CONVERSION OF WATER INTO STEAM.

1. The most common and general method of estimating the mechanical effect of any agent is by stating what weight it would raise a certain height, or to what height it would elevate a given weight. Thus, if we are told that such or such a mechanical agent is capable of raising ten tons a foot high, we have a distinct notion of its efficiency as a moving power. In this view of mechanical effect, it will be seen that we omit the consideration of time altogether; whether it be produced in a minute or in an hour, the mechanical effect accomplished is the same. We shall consider it in reference to *time* hereafter.

Now the questions I propose to examine are these:

2. What amount of mechanical effect is produced when a given quantity of water, as a cubic inch, is converted into steam?

3. To what extent, if at all, is such mechanical effect influenced by the pressure under which the water is evaporated or boiled?

4. Let it be remembered, that the water is supposed to be boiled in a close vessel, furnished with a valve loaded with a given pressure, so that the steam produced from the water shall have a pressure equivalent to that of the valve; in fact, according to our supposition, it must lift the valve to escape, and consequently its force must be in equilibrio with it. But for our present purpose we shall recur to a mode of illustration which will be more easily apprehended. Let us, as before, imagine a cubic inch of water placed in the bottom of a tube of indefinite length; a piston being placed in such tube, resting on the water, and so fitting the tube as not to permit the steam to escape. Let us suppose this piston, in the first instance, to press on the water with a force of 15 lbs., the surface of the piston in contact with the water having the magnitude of one square inch.

5. According to what has been already explained, it will be understood that when heat is applied to the water to convert it into steam, the piston will be forced upwards, to give room to the steam thus formed. Now, it has been shown that the room which the steam will thus require will be 1700 times more than its original volume in the liquid state. If then the section of the tube be a square inch, the piston will be raised 1700 inches high, in order to make room for the steam which will be produced. Thus a weight of 15 lbs. will be raised 1700 inches, or about 142 feet. The mechanical effect evolved in the evaporation of a cubic inch of water under these circumstances is therefore equivalent to 15 lbs. raised 142 feet high. But 15 lbs. raised 142 feet high is equivalent to 142 times 15 lbs. raised one foot high, or to 2130 lbs. raised a foot high. Now this weight is very nearly a ton, and as we are not here concerned with minute fractional accuracy, the following remarkable fact will follow, and may easily be retained in the memory.

6. *A cubic inch of water converted into steam under these circumstances will produce a mechanical force sufficient to raise a ton weight a foot high.*

7. But it may be objected here, that we have supposed the water evaporated under a particular pressure, and therefore at a particular temperature: may it not happen, therefore, that if evaporated under a different pressure and at a different temperature, a different mechanical effect will ensue?

To ascertain this, let us suppose the piston to be loaded with 30 lbs. instead of 15 lbs. We have already seen that in such case it would be raised to only half the height, for the steam produced would have double the density. Now 30 lbs. raised 71 feet is exactly equal to 15 lbs. raised 142 feet, and the same consequences would follow at any other supposable pressure.

SECTION V.—THE MECHANICAL EFFECT PRODUCED BY THE CONVERSION OF STEAM INTO WATER.

1. We have seen that a cubic inch of water makes a cubic foot of steam at the common pressure. If, then, a close vessel be filled with steam at this pressure, and be so exposed to cold that the steam it contains shall be converted into water, it will only occupy a cubic inch for every cubic foot of steam which the vessel previously contained. In fact, the vessel which was previously filled with steam will now have only a small quantity of water in it, the remainder of the space being a vacuum.

2. It is this property by which steam becomes instrumental in doing, by the mere agency of temperature, what is done by the expenditure of so much labour in air-pumps and common water-pumps.

3. By whatever agency a vacuum can be produced, by the same agency a given mechanical effect will follow; for if a piston be placed in the tube in which the vacuum is created beneath it, the pressure of the atmosphere will drive the piston down with a force of 15 lbs. for every square inch in the section of the piston. In air-pumps and common water-pumps, where the vacuum is created by pumping out the air, the amount of mechanical force expended in producing the vacuum is equivalent to the amount of mechanical force which the vacuum itself produces when made; but when a vacuum is made by converting steam into water, no mechanical force is expended in producing the effect; and consequently steam thus produces a mechanical force in its reconversion into water, as well as in its production from water.

SECTION VI.—HOW MUCH HEAT IS NECESSARY TO CONVERT WATER INTO STEAM.

1. Recurring again to the same mode of illustration, let us suppose the tube and piston as before, a cubic inch of water being below the piston; and let us imagine a lamp burning in a perfectly uniform manner under the tube, so that it shall impart heat to the water at an uniform rate. Let us suppose, at the commencement of the process, the water to be at the temperature of melting ice, but without having any ice in it. Let the time be then observed which shall elapse from the first moment of the application of the lamp to the moment at which the water begins to be converted into steam, and let us suppose this interval to be an hour. The application of the lamp being continued, as before, let the process of evaporation go on until all the water shall have been converted into steam. It will then be found that the time necessary to complete the evaporation will be $5\frac{1}{2}$ hours.

2. From this then it follows, since we suppose the action of the lamp to have been uniform, that to convert a given quantity of water into steam requires $5\frac{1}{2}$ times as much heat as would be necessary to raise the same water from the freezing to the boiling point.

3. This is a fact of such capital practical importance that it ought to be engraven on the memory.

It follows from it, that if a given weight of fuel is consumed in raising a quantity of water from the freezing to the boiling point, $5\frac{1}{2}$ times such weight of fuel will be consumed in converting the same water into steam.

4. There is another point of view in which it is both interesting and important to regard this fact.

If a thermometer be immersed in the steam which shall have been produced from the water, it will show that the steam has the same temperature as the water: thus, if the water were boiled under the usual pressure of 15 lbs. per square inch, its temperature would be 212°; the same would be the temperature of the steam into which it would be converted.

5. But it will be naturally asked in this case, what has become of the enormous quantity of heat which has been supplied by the lamp? If in an hour, while the lamp was raising the water from 32° to 212°, it imparted to such water a quantity of heat sufficient to raise it 180° higher in its temperature, it must have imparted an equal quantity of heat in each succeeding hour, and in 5½ hours it would of course have imparted as much heat as would have added 5½ times 180°, or 990°, to 212°, the temperature of the water, supposing the latter not to have been converted into steam: the water would thus, had it not being converted into steam, have been raised to the temperature of 1202°, or about 400° hotter than red-hot iron. But in the present case, in which the water passes from the liquid to the aeriform state, no augmentation of temperature has taken place at all; the steam which has received, and which actually contains all this enormous amount of heat, being no hotter than the water which contained nothing of it. Where is the heat then? And why is it not felt or indicated by the thermometer?

6. The answer to the first question is easy. It can be practically proved, as we shall presently show, that the heat is in the steam. But the second question reaches one of the final points of science, and cannot be answered. The heat which is in the steam, and yet neither sensible to the touch nor indicated by a thermometer, is said to be *latent.*

7. But we must not be deceived by the use of this word; it is merely a name given to the fact that the heat is not sensible, but it discloses to us no reason for that fact.

8. It is assumed that the heat has been employed in converting the water from the liquid to the aeriform state, and being employed in maintaining the water in such state, is not sensible to the thermometer. This, however, is after all but another mode of stating the fact, and is no explanation of it.

9. I observed that the 990° of heat is in the steam, though not sensible to the thermometer. We might perhaps be justified in considering this as proved, inasmuch as the lamp must be supposed to impart heat uniformly during its action, but we can give a very decisive practical demonstration of it.

10. Let a cubic foot of steam of the temperature of 212°, which has been produced from a cubic inch of water, be supposed to be contained in a close vessel. Let 5½ cubic inches of water at the temperature of 32° be injected into this vessel This cold water, mixing with the steam, will reduce the steam to water, or, to use a technical term, will *condense* it, and we shall find in the vessel 6½ cubic inches of water; namely, the 5½ cubic inches which were injected, and the cubic inch which was contained in the vessel in the form of steam, occupying a cubic foot, but which has now become water, and occupies only a cubic inch. These 6½ cubic inches of water will have the temperature of 212°; that is to say, the same temperature as that of the steam which was condensed.

Now it is evident that in returning to the state of water, the steam has given out as much heat as has been sufficient to raise the 5½ cubic inches of water which were injected into the vessel from 32° to 212°; and yet the cubic inch of water into which such steam has been converted has itself the temperature of 212°, being the same as that which it had when in the form of steam. It is clear then that the 990° of heat which were in the steam are now in the 5½ cubic inches of water which were injected, and have raised this, as must necessarily have been the case, from 32° to 212°

11. It is therefore demonstrated that steam has in it as much heat insensible to the thermometer and to the touch as would be sufficient to raise $5\frac{1}{2}$ times its own weight of water from the freezing to the boiling point.

12. This result has an important relation to the economy of steam power. The heat supplied by any fuel of uniform quality, and used in an uniform manner, will be proportionate to the quantity of such fuel consumed. It follows, therefore, that it requires $6\frac{1}{2}$ times as much fuel to convert water into steam, supposing the process to commence with the water at 32°, as would be sufficient to boil the same quantity of water. If the process be supposed to commence at the more ordinary temperature of 60°, then a still greater proportion of fuel will be necessary for vaporisation.

13. I have supposed throughout this exposition that the water has been evaporated under the common pressure of 15 lbs. per square inch, and at the temperature of 212°; but it may be asked, what would be the result if the process were conducted under a different pressure and at a different temperature? Might it not happen that the vaporisation would be effected with a greater economy of heat, which would be an important fact in the application of steam power?

14. Such, however, is not the case. It is found that no matter what the pressure may be under which the process is conducted, the same lamp, or other uniform source of heat, acting on the same water, will take exactly the same time to convert it into steam. It is true that the quantity of what is called *latent heat, or heat of conversion* will be different, and will be diminished as the pressure is increased. Thus each degree which is added to the temperature at which the water boils by increase of pressure will be subtracted from the latent heat of the steam. The manner in which this remarkable fact is usually expressed is, that the sum of the latent and sensible heats of steam is always the same, namely, about 1200°.

15. Thus if water be evaporated under such a pressure that its boiling point shall be 400°, then the latent heat of the steam produced from it will be 800°; if it be evaporated at 300°, the latent heat will be 900°, and so on.

16. This is curious; but the important fact is, that the consumption of fuel in the conversion of water into steam is the same, whatever be the pressure of steam produced.

SECTION VII.—THE MECHANICAL FORCE OF STEAM BY ITS EXPANSION.

1. We have seen how a piston is urged from one end to another of a cylinder with a definite force by allowing steam to flow in upon it, and that increased efficacy is given to this by creating a vacuum on the side towards which the piston moves. The steam in this case is supposed to flow from the boiler, and to press the piston forward with a certain uniform force. The piston advances because a fresh portion of steam which enters the cylinder requires more room, to give it which the motion of the piston is necessary.

When as much steam has entered in this manner as is sufficient to fill the cylinder, then the piston will be driven to the extreme end of it. Now, it is well to observe that in the production of this effect no quality proper to steam, or which distinguishes steam from any other fluid, is concerned.

If a liquid (water, for example) were made to flow into the cylinder with the same pressure and in the same quantity, it would produce precisely the same effect; in fact, the steam acts thus not because it is an *elastic* fluid, but because it is a *fluid*, and is urged from the boiler with a certain force.

2. I now come to notice, however, a mode of action in which steam performs what

an inelastic fluid could not perform ; one, in short, in which it produces a mechanical effect in virtue of that property which steam enjoys in common with air and other gaseous fluids, and in which inelastic fluids, such as water, do not participate.

3. Let us suppose that the steam flowing into the cylinder acts upon the piston with a certain definite force, as one ton, and continues so to act as long as it enters the cylinder.

4. Now let us imagine that when the piston has been thus pushed to the middle of the cylinder, the aperture at which the steam enters is suddenly closed, so as to prevent any fresh supply. The piston will then be no longer pushed forward by any increased quantity of steam coming from the boiler. It will nevertheless be pressed by the elastic force of the steam, just as it would be by the elastic force of air under the same circumstances ; it will still be pressed on by a force of one ton, supposing that no adequate resistance obstructs its motion. It will not therefore come to rest, but will continue to advance. As it advances, the steam, expanding into a larger space, will acquire a proportionally diminishing elastic force, and will press on the piston with a force less than a ton, in exactly the same proportion as the space occupied by the steam is greater than half the cylinder. Ultimately, when the piston arrives at the end of the cylinder, the steam, which originally filled half the cylinder, will fill the whole cylinder ; and the pressure upon the piston, which was originally a ton, will then be in round numbers half a ton.

5. It appears evident, then, that while the piston is thus moved through the latter half of the cylinder, it is urged by a continually decreasing force, which begins with a ton, and which ends with half a ton.

6. If we could calculate the average amount of this moving force, we could at once declare the mechanical effect which is produced through the latter half of the cylinder in virtue of the expansive power of the steam.

7. At first view it might appear that the average pressure must be a mean between the original pressure of a ton and the final pressure of half a ton, and that such mean would therefore be three-quarters of a ton. But such a conclusion would be erroneous.

8. The method of calculating the exact average of a force decreasing in the manner we have described requires principles of the higher mathematics. By the application of these principles it appears that the exact average of the varying pressures, in the case we have described, would be 1545 lbs.

9. The mechanical effect, therefore, obtained in this way from the expansive action of the steam would be equal to 1545 lbs. driven through a space equal to half the length of the cylinder. It appears, then, that nearly 75 per cent. has been added to the original mechanical efficacy of the steam by this expedient.

10. It may be asked whether there be any limit to the application of this principle. It is known that other fluids, having the same natural properties as steam, are capable of expansion indefinitely, and it might at first be imagined that there is no limit to the augmentation of the mechanical force which might thus be obtained from steam ; but practical considerations shew that there are not only limits, but comparatively narrow ones, to its application.

11. It will be observed that the piston, which is urged by the force of expansive steam, is acted upon by a continually diminishing power of impulsion. When the pressure of the steam becomes by expansion less than the load which such piston drives through the intervention of machinery, including the natural resistance of the machinery itself, then it is clear that the moving power will cease to be efficacious, and that the piston must come to rest.

12. The inertia of the machinery may continue the motion somewhat longer than

the moment at which an equilibrium takes place between the resistance of the load and the pressure on the piston, but this effect must soon expire.

13. The expedient by which the expansive principle may be most conveniently extended is to use, in the commencement, steam of high pressure and great density; such steam may allow of considerable expansion before it loses so much of its force as to be reduced to an equilibrium with the resistance to the piston.

14. In all cases the expansive principle evidently involves a continual variation in the impelling power of the piston.

Now, it seldom happens that there is any similar variation in the resistance which the piston is required to overcome; and in that case an irregularity of action would ensue. In the commencement, the energy of the impelling force being greater than the resistance, an accelerated motion would be produced, and towards the end, the impelling force becoming less than the resistance, a retarded motion would be the effect. A great variety of contrivances have been suggested by mechanical inventors to equalise this varying action,—

15. The most common and the most beautiful of which is the *fly wheel.* This is a heavy wheel of metal, well centred, and turning upon its axle with but little friction, so that the force necessary to keep it in uniform motion is inconsiderable. The varying action of the piston is transmitted to this wheel. When the impulsive force is greater than the resistance to the load, the surplus is imparted to the wheel, to which it gives a slight increase of speed. Owing to the great mass of matter in the wheel, an increase of speed which is scarcely sensible absorbs an immense amount of moving force. When the impulse of the piston by the expansion of the steam becomes less than the resistance, then the momentum of the wheel acts upon the load, and that portion of surplus force which was previously imparted to it is given back, and the wheel assists, as it were, the diminished pressure and the piston in moving the load when the latter becomes enfeebled by the extreme expansion of the steam.

16. The fly-wheel is thus, as it were, a magazine of force which gives and takes according to the exigencies of the machinery. When the moving force is in excess, the fly-wheel absorbs the surplus; when the moving force is deficient, the fly-wheel gives back what is absorbed.

17. Cases occur, however, in the arts in which the resistance to be overcome by the piston is of a gradually decreasing nature. In such cases, the expansive action of the steam, being also gradually decreasing, may be kept in equilibrio with the work without the intervention of the equalising action of the fly-wheel. Thus if the piston work a pump by which a column of water is raised, which column flows off at the top, the length of the column, and therefore its weight, is greatest when the buckets of the pump begin to ascend, and least when they arrive at the summit of their play. The weight in the buckets is in this case of continually decreasing amount, like the decreasing force of expanding steam.

18. But, in most cases, some equalising contrivance is necessary where the expansive principle is extensively used, and where anything approaching to uniform action is necessary.

19. The expansive action of steam is applied in steam engines in various ways, but by far the most usual is that which we have described in the above illustration, by cutting off the supply of steam at some point before the completion of the stroke. In some cases it is cut off at half-stroke, in some at one-third, and in some at much smaller fractions of the entire stroke. In other cases a small and a large cylinder fitted with pistons are placed side by side and the steam admitted at a high pressure into the smaller cylinder is there cut off and allowed to expand into the larger cylinder.

SECTION VIII.—HOW A VACUUM IS PRODUCED WITHOUT COOLING THE VESSEL CONTAINING THE STEAM.

1. With whatever force the piston be impelled, the effects of that force will be evidently augmented by an ability to produce a vacuum, or even a partial vacuum, in that part of the cylinder towards which the piston moves.

2. It has been already shown that this may be accomplished, if the cylinder be previously filled with steam, by exposing the steam which has filled it to the contact of cold. If a cubic foot of steam at 212° be reconverted into water by cold, it will be reduced to a cubic inch of that liquid, and we shall have the entire cubic foot, minus one inch, a vacuum; and therefore, for every cubic foot of steam in the cylinder we shall have a cubic foot of vacuum minus one cubic inch.

3. But here we encounter a practical difficulty which long remained without solution. If we produce the vacuum by cooling the cylinder, and thus condensing the steam it contains, we shall be obliged, on the next stroke of the piston, when the cylinder must be refilled with steam, to raise its temperature again to that of the steam it is intended to contain; for otherwise the cylinder itself would condense the steam intended to fill it. Now, the heat necessary thus to warm the cylinder at every stroke of the piston would entail upon us an enormous waste of fuel; yet to this waste was every steam engine exposed from the date of the invention of that form of the engine called the atmospheric engine, in the first years of the last century, until the year 1763, when Watt solved the problem *to condense the steam without cooling the cylinder*.

4. Like almost all discoveries of the first order in the arts, this seems astonishingly obvious now that we know it; and one only wonders how it could remain for more than half a century undiscovered, human invention moreover being stimulated by the prospect of a reward which in the case of Watt proved to be a princely fortune.

5. The first expedient suggested in the progress of discovery for the production of a vacuum in the cylinder, by the condensation of the steam within it, was to cool the cylinder itself by the application of cold water on its external surface.

This process was slow, and consequently retarded injuriously the rate of action of the machine. Accident suggested a much more prompt and effectual method.

It happened that a leak took place in the bottom of a cylinder, at a point where a supply of cold water was placed; the water, pressed by the atmosphere through the hole, spirted up in a jet within the cylinder, and in an instant, by its contact with the steam, condensed it and produced a sudden vacuum. The unusually rapid descent of the piston attracted the attention of the Engineer, the cause was investigated, and the method of cooling the cylinder on its exterior surface was thenceforward abandoned. A cock or valve was placed at the bottom of the cylinder, by which cold water was injected when it was required to condense the steam, and another was provided by which the water and condensed steam were allowed to escape. In this manner the engine continued to be worked until the application of the invention, which, with so many others, has conferred immortality on the name of Watt.

6. Although the condensation by jet has the advantage, as we have stated, of being prompt, yet the cylinder was still cooled, and the waste of fuel attendant upon reheating it still took place. It is true that a jet of water would in the first instance condense the steam within the cylinder without materially lowering the temperature of the cylinder itself; but the effect would be that the heat of the cylinder, acting on the water contained within it, would immediately reconvert a portion of such water into steam, and destroy the vacuum before it could take effect upon the piston. It

was therefore necessary to throw in by the jet as much cold water as was sufficient not merely to condense the steam, but also to cool the cylinder down to the temperature of at most 100°; and even at this temperature a portion of the vapour was still uncondensed, which impeded injuriously the action of the machine.

7. The invention of Watt not only had the effect of producing an almost perfect vacuum, but it did so without in the slightest degree lowering the temperature of the cylinder. The idea occurred to Watt of placing near the cylinder another vessel submerged in cold water, and having a jet of cold water constantly playing within it. Whenever it was desired to condense the steam in the cylinder, he opened a communication by a cock or a valve between this vessel and the cylinder, and immediately the steam, by its elastic force, rushed into this vessel, and was instantly condensed, leaving in the cylinder an almost perfect vacuum, and at the same time exposing the cylinder to no cold which could in the slightest degree lower its temperature.

8. The vessel here described, immersed in a cistern of cold water, and having a jet playing in it was called a *condenser*. By the continuance of the process just described such vessel would, after a time, not only be filled with water supplied from the jet, and the condensed steam proceeding from the cylinder, but it would also contain more or less air which would enter in a fixed form in the water, and which would be liberated by the warmth of the steam condensed by the water. This air would vitiate to some extent the vacuum in the condenser, into which it would pass in virtue of its elasticity. These impediments were surmounted by the adjunction of a pump to the condenser, by which the water supplied by the jet and the condensed steam, as well as the air just adverted to, were constantly pumped out.

9. This is called the *air-pump*.

10. The water surrounding the condenser, unless it were changed, would in time become warm, and fail to effect the condensation. This is remedied by the application of a pump and waste pipe to the cold cistern in which the condenser is submerged. The pump continually supplied cold water, which, by its comparative weight, had a tendency to sink to the bottom; and the waste pipe, placed near the surface, let escape the warm water, which, by its comparative lightness, ascended: thus, with these arrangements, the method of separate condensation became complete.

11. The effect of this invention, with a few others, which will be described hereafter, was to save about 75 per cent. of the fuel consumed by the steam engines as previously worked. Watt and his partner Boulton were content to receive, as their reward for this gift to the arts, one-third of the saving which they effected; and this one-third proved to be sufficient to enable each of these illustrious men to leave to their descendants magnificent fortunes.

SECTION IX.—THE MECHANICAL ACTION OF STEAM MAY BE AUGMENTED BY HEAT IMPARTED TO IT DIRECTLY.

1. In all the ordinary applications of steam, the heat imparted is applied to water from which the steam used for mechanical purposes is raised. Heat, however, may be imparted directly to the steam itself, after it has been separated from the water, and, when so applied, it will augment in a certain proportion the mechanical efficacy of the steam.

It has been thought by some projectors that heat applied in this way might be rendered more efficacious than when applied in the evaporation of steam from water. It may therefore be worth while to explain here to what extent the mechanical power of steam can be augmented in this way.

2. It is a remarkable fact, that the effect of heat applied to air and all species of

gases in augmenting their volume is precisely the same. It is found that if air or any species of gas be confined within a certain volume, and that heat be applied to it until its temperature be raised one degree, its elastic force will be augmented by one 480th part of its whole amount. Thus if a certain surface of the vessel which contains it suffer a pressure from its elastic force of 480 lbs., the same surface will suffer a pressure of 481 lbs. from the temperature of the air or gas being raised one degree.

3. Now it is still more remarkable, that the very same law applies to every species of vapour, that of water included. If then a cylinder containing steam excluded from contact with water be exposed to any source of heat, it will receive the above augmentation of pressure for every degree by which its temperature is elevated. This increase amounts, in round numbers, to one-fifth per cent. of the whole mechanical effect.

4. It is scarcely necessary to say that the same quantity of fuel which would produce this increase of mechanical effect, applied directly to a vessel containing steam, would produce a greater mechanical effect, applied to a boiler to produce steam from water.

It is therefore not necessary to dwell further on this principle, as invention has not yet profitably employed it in the case of steam.

SECTION X.—HOW A PISTON IS MADE TO MOVE ALTERNATELY FROM END TO END OF A CYLINDER WITH A DEFINITE MECHANICAL FORCE.

1. It is evident that if steam can be admitted on one side of the piston, and withdrawn on the other, the piston will move in obedience to the pressure on the side at which it is admitted.

2. If, when the piston arrives in this manner at the end of the cylinder, the steam which has impelled it be withdrawn, and at the same time steam be admitted on the other side, the piston will move back again from exactly the same cause.

Thus to produce the alternate motion of the piston, it is only necessary to provide means for the alternate admission and escape of the steam at each end of the cylinder.

3. This supposes two apertures of some kind at each end, one for the admission and the other for the escape of the steam : it supposes also one of these apertures to communicate with the boiler, where the steam is generated, and the other to communicate with the condenser, where the steam is destroyed.

4. It supposes, moreover, some means of alternately stopping and opening each of these apertures.

The means whereby this is effected are very numerous.

5. It may be done by stoppers which fit steam-tight into holes, from which they are lifted or drawn, and to which they are returned alternately, just as the stopper of a decanter would be, only that they are made more conical, in order that they may be more suddenly opened and closed. These are usually made of brass or gun-metal, and may be ground so as to fit with great precision.

These contrivances are called *conical valves*. Those which open a communication with the boiler are called *steam valves*, and those which open a communication with the condenser are called *exhaust valves.*

6. Now supposing that we are provided with such contrivances, and are supplied with the proper mechanism for opening and closing them, nothing can be more simple than to work the engine.

7. Although it is not necessary that the cylinder be placed in a vertical position, and very often it is not so, yet, for the convenience of explanation, we shall here suppose it in that position, and we shall distinguish the two steam valves as the

upper and *lower*, and the same with the two exhaust valves. Let us then suppose the piston to begin its motion at the top of the cylinder, and let the cylinder under it be imagined to be filled with steam, all the valves being closed. Let the upper steam valve and the lower exhaust valve be simultaneously opened. Steam will flow through the upper steam valve above the piston, and the steam below the piston will flow through the lower exhaust valve into the condenser, where it will be destroyed. We shall have a vacuum under the piston, and the pressure of steam above it. The piston will therefore descend to the bottom of the cylinder.

8. When it arrives there, let the two valves, which have just been supposed to be opened, be closed. The top of the cylinder will now be shut off from the boiler, and the bottom from the condenser. At the same time, let the lower steam valve and the upper exhaust valve be opened. The steam which filled the cylinder above the piston will immediately rush to the condenser through the open exhaust valve, where it will be destroyed, and steam from the boiler will pass below the piston through the lower steam valve. Steam pressure will therefore act below the piston while there is a vacuum above it, and the piston will ascend until it reaches the top of the cylinder. The constant repetition of the same process of opening and closing the valves in pairs would obviously in this manner continue the alternate action of the piston from end to end of the cylinder.

9. In the earlier steam engines this process of opening and closing the valves was executed by the hand of an attendant, and, like all constant mechanical action which depends on the human will, was done irregularly. It soon became apparent that the piston itself could be made to execute this with the most perfect certainty, regularity, and precision. Tradition says that an uneducated child, named Humphrey Potter, was the inventor of this improvement, by which the steam engine first became a self-acting and self-regulating machine.

10. From what has been above explained it will be evident, that although there are four independent valves, there is in reality only a single motion, and that all the four may be easily managed to be connected so that the motion to be imparted to them may be effected by a single impulse proceeding from any convenient part of the machinery.

11. When the piston arrives at the top of the cylinder, two valves—the upper steam valve and lower exhaust valve—are required to be opened; and at the same moment the two other valves—the lower steam valve and upper exhaust valve—must be closed. Now as all these movements are simultaneous, it may be easily imagined that the four valves may be so connected that a single movement imparted to them should open one pair and close the other pair.

12. When the piston arrives at the bottom of the cylinder, a single motion in the contrary direction will evidently effect the object to be attained, that is to say, to open the lower steam valve and upper exhaust valve, and close the upper steam valve and lower exhaust valve.

13. These communications between the ends of the cylinder and the boiler on the one hand, and the condenser on the other, are often governed by means even more simple than by the valves we have just described.

14. The two openings or ports leading to either end of the cylinder are sometimes made in flat surfaces upon which metal covers or slides are made to move backwards and forwards by means of a rod actuated by an eccentric on the working shaft. The slide opens and closes the parts alternately, and by the same action causes the escape of the waste steam into the condenser, or into the atmosphere. The slide works in a chamber called the valve chest, into which steam passes from the boiler.

15. These contrivances are called *slides*.

16. If the steam be used expansively, by shutting it off before the completion of the stroke, the times of opening and shutting the several apertures will not be the same.

17. The opening by which the steam is admitted will in that case be closed at the moment when the piston has completed a certain part of the stroke, and the valve for the admission of steam at the other end must not be opened till the end of the stroke.

18. When a cylinder is so worked, there will then be three epochs in each stroke at which the valves must be acted upon,—at the commencement when the steam is first admitted to impel the piston, at some intermediate point when its influx is stopped, and at the extremity when it is let in on the other side. If conical valves be used, such as we have first described, each moving independently of the other, it is easy to conceive how these effects may be produced; but even with slides they are also managed by so adjusting the slide to the opening, that by two successive motions, made at different points of the stroke, the effect is produced. At the commencement, the slide being advanced through a certain space, the steam is admitted on the one side of the piston and withdrawn from the other; at an intermediate point, the slide being further advanced, the influx of steam is shut off, but the efflux on the other side still permitted; at the termination of the stroke, another movement of the slide admits the influx on the other side, and the efflux on the opposite side.

19. The efficiency of the operation of the piston greatly depends on its being steam-tight in the cylinder. The least leakage from the one side to the other would cause the steam to escape to the vacuum side. It is true that, arriving there, it would immediately rush to the condenser, so that it might not sensibly impede the action of the piston, but it would still be a source of waste of power.

20. Pistons are rendered steam-tight by metallic packing.

21. Between the two plates forming the top and bottom of the piston are placed a number of metallic rings, one above the other, so as to fill the space between the two plates, and having their diameters a little less than that of the cylinder: these rings are usually cut into three or four segments, the points at which each ring is cut not corresponding with those at which the rings above and below are cut. Within these segments are placed springs, which, acting from the centre of the piston, urge the segments against the surface of the cylinder. The construction of these and the form of the cylinder itself have been brought to such a degree of precision, that these pistons act with complete efficacy; and use, instead of injuring, improves them.

22. In all the preceding explanations it has been supposed that the steam is admitted at either end of the cylinder at the moment that the piston has arrived there, and is about to commence its action in the opposite direction. In practice, however, it is convenient to admit the steam a little before the moment when the piston reaches the extremity of the cylinder: this is attended with the advantage of assisting to break the shock which would attend the sudden change in the direction of the motion of the mass of matter composing the piston and rod, and the other parts of the machinery which partake of their alternate motion. The steam admitted just before the motion of the piston is reversed, acts as a sort of cushion to receive the piston.

23. These and other matters of practical detail in the operation of the engine, render the time of opening the valves a very important matter, and machinery is accordingly provided for regulating the moment of their opening with the greatest certainty and precision.

SECTION XI.—HOW THE ALTERNATE MOTION OF THE PISTON-ROD IS CONVEYED TO THE WORKING BEAM.

1. In most stationary engines of the larger class, the power exercised by the piston in a steam engine is in the first instance imparted to a beam called the *working*

beam, which is supported on a fixed axis, and which vibrates alternately upwards and downwards.

Now, it may at first view appear that we might at once impart the motion of the piston to the beam by attaching its extremity to that of the beam by a common joint and pin, but the slightest reflection will show that such an arrangement would be incompatible with what has been already stated.

2. It will be remembered that the piston-rod is a thick rod of iron, accurately formed and polished, that it is firmly attached to the centre of the piston, and that the construction and operation of the cylinder and piston require that the rod should accurately move in a straight line upwards and downwards. Now, the end of the beam, which vibrates alternately on a horizontal axis, will move alternately upwards and downwards, but not in a straight line. It will move alternately in the arc of a circle, the centre of which will be that of the axis on which the beam vibrates. If, then, we attempt to connect immediately the end of the piston with the end of the beam, the consequence will be that the end of the piston, following the motion of the end of the beam, will be moved alternately upwards and downwards, in a circular arc, and consequently would be strained or bent, and its action in the cylinder disturbed.

3. There are several ways of surmounting this difficulty, all of which consist in interposing between the end of the piston-rod and the end of the beam some piece of mechanism which will allow the rectilinear motion of the one and the alternate circular motion of the other.

4. The most simple expedient of this kind consists of a rod of metal, working at one end by a pivot on the beam, and at the other by a pivot on the end of the piston-rod. In this case, however, there would still be a liability to straining the piston-rod from its rectilinear motion, were it not regulated by some species of guide. A common method of effecting this is to attach at the top of the piston-rod a cross piece so as to make with it a form like the letter T. The ends of this cross piece are made to slide on fixed upright rods, or between fixed flat plates of iron, called "*Guides*," so that these last may resist any tendency to strain the piston. The joint or joints connecting the piston with the end of the beam may be attached to the ends of the cross piece.

5. It is not indispensably necessary that a beam should be employed at all, and in some engines of small magnitude and compact form it is omitted. A rod is brought from the cross head of the piston directly to the crank pin of the main working shaft.

6. In many cases, and especially in the large class of steam-engines used in England in manufactories, the piston-rod is connected with the beam by a contrivance called a *parallel motion*. This is a combination of rods, so arranged and joined together that while one of their pivots is moved alternately in a circular arc, like the end of the beam, some point upon them will be moved alternately upwards and downwards in a straight line.

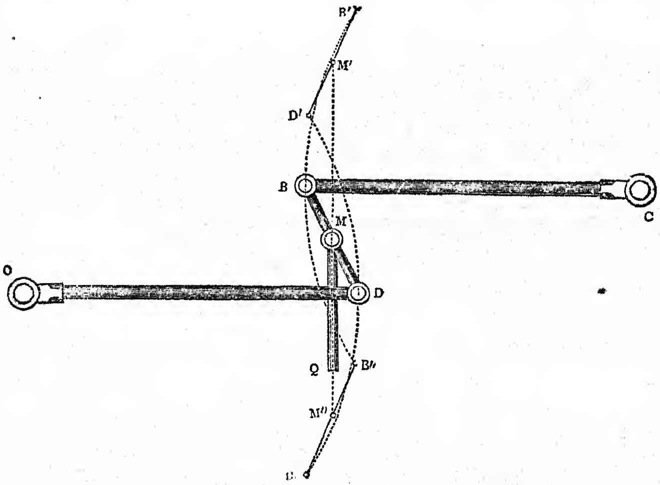
7. A great variety of combinations and proportions are capable of effecting this with sufficient precision for all mechanical purposes, but that which is best known as the parallel motion, and which is due to the invention of the celebrated Watt, is in principle as follows. (See the figure in the next page.)

8. Let two equal rods C B and O D be attached by pivots to two fixed points at C and O, on which they shall be at liberty to play alternately upwards and downwards in the circular arcs B′ B″ and D′ D″; but let their play be limited to small arcs. Now, let a third rod B D be connected by pivots with the ends of the two former.

Let a point M be marked at the middle of the rod B D. Now if C B be made to vibrate on its centre C alternately in the arc B′ B″, which will cause at the same time

O D to vibrate alternately in the arc D′ D″, it will be found that the point M will ascend and descend in a line M′ M″, which will not deviate sensibly from a straight line, in a vertical direction; in fact, if a pencil were attached to the point M, and a surface held behind it, such pencil, by the motion of the rods, would trace a vertical line upon the surface.

Now, if we imagine O B to represent the beam of the engine, and O D and B D rods connected with it in the manner already described, O being attached to a fixed pivot,



then the point M, being attached to the top of the piston-rod, will move with it freely upwards and downwards in a true vertical line, and will, through the combination of rods just described, impart motion to the end of the beam B.

9. To demonstrate strictly this, would require the application of mathematical principles not compatible with our present object; nor, indeed, is it strictly true, in a geometrical sense, that the motion of the point M takes place in a straight line; its deviation, however, from a vertical line, within the limits of the play given to the beam and piston, is so extremely small as to have no practical effect whatever.

The general effect of the combination here described may be understood thus:—When the point B is moved upwards to B′, the upper extremity of the rod B D is drawn a little to the right, and at the same time the lower extremity D, being moved to D′, is drawn a little to the left. When the extremity B descends to B″, the extremity D descends to D″, and the ends are again drawn the one a little to the right and the other a little to the left. It will be easily understood that in this case, while the ends of the rod B D are thus alternately made to move right and left, there will be an intermediate point of it which will neither deviate on the one side nor on the other. The upper half of the rod, in fact, is continually inclined towards the right, and the lower half towards the left, the middle point being affected by neither motion, and therefore being moved vertically upwards and downwards in a direct straight line. This is the principle of the parallel motion.

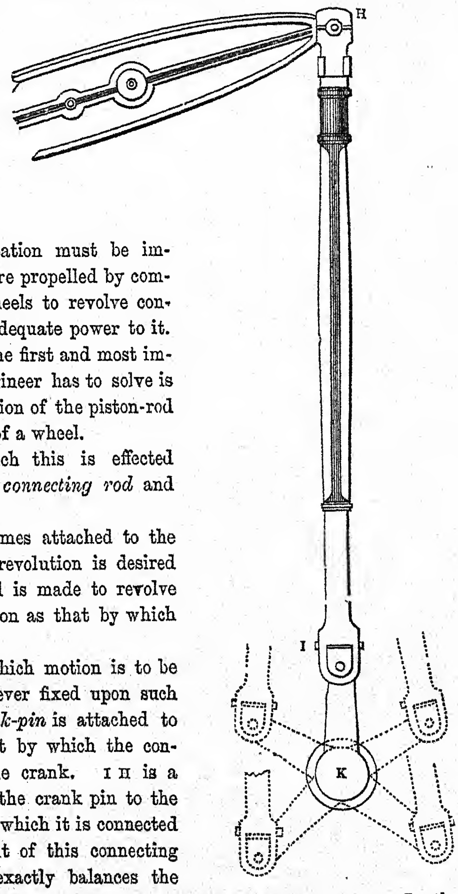
10. In its practical application it appears somewhat more complicated, for in order to accommodate the arrangements of the beam and piston-rod, a great number of rods and joints are necessary to be used; but these are mere matters of mechanical convenience, and have no effect upon the principle of the arrangement.

It is therefore now apparent that the alternate motion of the piston-rod upwards and downwards in a straight line imparts a corresponding alternate motion to the end of the working beam in a circular arch.

11. Although we have, as usual, here described the arrangements as if the cylinder were vertical and the beam placed over the piston-rod, this position is neither necessary nor is it invariably adopted. Sometimes the beam is placed below the cylinder, and the rods of the parallel motion or connections, with the cross head and guides, are made of sufficient length to extend down to the beam. Sometimes the cylinder is horizontal and the beam vertical, and cases even occur in which it is found convenient to place the cylinder in an inclined position; but all these are matters of arrangement to be determined by the circumstances in which the engine is applied, and have nothing whatever to do with its mechanical principle.

SECTION XII.—HOW THE ALTERNATE MOTION OF THE WORKING BEAM PRODUCES A MOTION OF CONTINUED ROTATION.

1. Of all sorts of motion, that which is most frequently required n the arts is one of continued rotation. Mills in factories of every kind are impelled by machinery which receives its motion from a wheel kept in constant rotation.



Ships impelled by steam engines over the deep are driven by paddle-wheels or screws, to which constant rotation must be imparted. Carriages on railways are propelled by compelling one or more of their wheels to revolve continually by the application of adequate power to it. This is so evident, that one of the first and most important problems the steam engineer has to solve is how to make the alternate motion of the piston-rod produce the continued rotation of a wheel.

2. The contrivance by which this is effected almost universally is called a *connecting rod* and *crank*.

The crank is an arm sometimes attached to the centre of the wheel to which revolution is desired to be imparted, and the wheel is made to revolve by it by the same mode of action as that by which a winch turns a windlass.

Thus, if K be the centre to which motion is to be imparted, K I is an arm or lever fixed upon such centre. A pin called the *crank-pin* is attached to this at I, which forms the joint by which the connecting rod is united with the crank. I H is a strong iron rod extending from the crank pin to the end of the working beam, with which it is connected by a similar pin. The weight of this connecting rod is so adjusted that it exactly balances the weight of the piston and its rod attached to the other end of the beam. In the

figure the crank is represented by dotted lines in the different positions which it assumes as it revolves. As the end of the beam is moved upwards and downwards, the crank will be turned round the centre K, and a motion of continued rotation will be produced, which will be communicated to any wheel fastened upon the axle K.

3. To make the action of the piston upon the crank perfectly clear, let it be supposed that the piston is in its descending stroke. The force of the steam upon it is imparted by the rod and the intermediate mechanism to the end of the beam which is drawn down. At the same time the other end of the beam, with the connecting rod, is drawn up. The crank is thus made to ascend from its lowest to its highest position, to which it arrives when the piston has reached the bottom of the cylinder. When the piston ascends, the force of the steam is in like manner transmitted to the beam by the piston-rod, which is made to ascend, and the opposite extremity, with the connecting rod, descends, by which the crank is driven to its lowest position on the side opposite to that on which it ascended, and thus a motion of continued rotation is produced.

4. But in this action there are particulars necessary to be noticed. There are two positions which the crank assumes, in each revolution, at which the force of the piston can have no effect in continuing its motion: these positions are those which the crank assumes when the piston is at the top and at the bottom of the cylinder, the points at which it changes the direction of its motion. When the piston is at the bottom of the cylinder, the crank-pin is immediately above the axis to which the crank is attached: in this position the force of the piston would have no other effect than to press the crank perpendicularly upon the axle, and evidently would have no effect whatever in making it revolve. If we were to suppose then the entire machinery at rest in this position, the steam acting on it could not put it into motion.

5. Again, if we suppose the piston to be at the top of the cylinder, the crank-pin will then be at its lowest point, and will be directly under the axle: the effect of the steam acting above the piston would then be to press the crank-pin upwards against the axle, but it could have no influence in turning it. If, therefore, the machinery were at rest in this position, it could not be put in motion by the steam.

In any intermediate position, however, the connecting rod would act on the crank with a leverage more or less effective, and would move it.

6. The two points which we have here described, at which the crank-pin assumes its highest and lowest position, are usually called the *dead points.*

Now it may be asked why the engine does not cease to move every time the crank-pin arrives at these dead points, seeing that there the moving power, however energetic, can have no effect on it.

7. The answer is, that the machinery is extricated from this mechanical dilemma in virtue of the common property of matter called *inertia*, by reason of which, when it has acquired any definite motion in any certain direction, it will not suddenly stop, even though it be impelled by no external force, but will continue to move until the momentum it had acquired be exhausted by friction and other resistance.

8. Since, then, the motive power continues to exercise more or less force up to the dead points, the machinery, arriving at them, has some definite motion, and the momentum consequent upon that motion carries the crank out of the critical position we have referred to.

9. But, independently of the dead points, there are other circumstances attending the action of the connecting rod on the crank, which are necessary to be explained. By the intervention of the beam, the force of the piston is transmitted to the crank-pin in the direction of the connecting rod. Now by observing the diagram above given, shewing the successive positions of the connecting rod and crank, it will be

seen that twice in each revolution the connecting rod is at right angles with the crank, but that in other positions it is more or less oblique to it; the extremes of the obliquity terminating alternately in the dead points, in one of which the connecting rod and crank are brought into a continued straight line, and in the other the crank is as it were doubled on the connecting rod.

10. Without resorting to the language of technical geometry, it will be apparent that the action of the connecting rod on the crank is most energetic when they are at right angles: and that according as they become more and more oblique, and approach the dead points, the action becomes less and less effective. It diminishes rapidly in approaching these points, and is altogether extinguished on arriving at them. It appears then that the action of the connecting rod on the crank is subject to a regular variation in each semi-revolution: a maximum when they are at right angles, it diminishes, and at length vanishes when it arrives at the highest point; then, in descending, it re-appears, augments, and is a maximum at the point where they are at right angles; then it again diminishes gradually, and ultimately vanishes at the lowest point; having passed which, it again re-appears, augments, and is a maximum when it assumes its rectangular attitude.

11. Now although the inertia of that portion of the machinery which is once put in revolution be sufficient to prevent the motion from ceasing, and the engine coming to a dead lock when the crank-pin comes to the dead points, yet it is not generally sufficient to prevent a very great inequality of motion from arising from the cause which we have here explained. An expedient accordingly has been resorted to, which perfectly counteracts this inconvenience, and equalises the motion. This expedient is the fly-wheel, which we have already described.

12. The fly-wheel is placed on the same axle K as the crank, and it is made to revolve simultaneously with the crank. This wheel is so nicely balanced on its centre, and moves with so little friction, that it absorbs a very inconsiderable portion of the moving power. It is usually made of very large diameter, and its ring or circumference is composed of a very ponderous mass of metal. All this metal is put in motion by the moving power, and, from its great mass, has a considerable momentum even when the velocity is moderate. When the crank is at the dead points, this mass, by its momentum, continues the revolution, and carries the crank into a new attitude, where the moving power exercises an influence on it. When the crank and connecting rod are in that position in which their action is most energetic, the fly-wheel absorbs a part of the moving power. As the crank approaches the position in which the action of the moving power upon it becomes enfeebled, the fly-wheel gives back to the machinery such surplus power as it received when the action of the crank was most energetic.

13. Between the fly-wheel and the engine there is, therefore, a continual reciprocity of action and interchange of power, which in practice completely equalises the velocity; and there is in fact no perceptible difference between the speed of the movement at the dead points, where the moving power loses its influence, and at the middle of the stroke, where its action is most effective.

14. To minds not very familiar with mechanical considerations, it may seem extraordinary that the intense action of the moving power upon the fly-wheel at the middle of the stroke should not at these points produce a perceptible acceleration in its motion, and a corresponding irregularity, therefore, in the motion of the machinery which it drives; but it must be considered that the excessive mechanical force exerted at the middle of the stroke is imparted to a great mass of metal collected in the rim of a very large wheel. Now the velocity which a given force produces is diminished in the direct proportion of the mass of matter to which it is

imparted: thus a force which would give a certain speed to a ton of metal would give only a tenth part of such speed to 10 tons. The weight collected in the rim of the fly-wheel is so great that the excess of power of the engine at the middle of the stroke, when imparted to it, produces an inconsiderable increase of speed. But this increase of speed, inconsiderable as it is, is produced on the circumference of a very large circle, and the mass of matter thus moved must be carried through a very considerable space in making even a single revolution. Thus, what between the great mass of metal collected in the rim of the fly-wheel and the great diameter of the fly-wheel itself, the unequal action of the crank is rendered absolutely imperceptible.

15. In some elementary works on the steam engine, proceeding from persons who, however respectable their practical attainments, are deficient in mathematical knowledge, the crank is represented as an imperfect contrivance, and an extensive source of waste of power, owing to unequal action.

Nothing can be more fallacious than the reasoning of such writers. It can be demonstrated by the most strict geometrical reasoning, and the result is verified by experience, that in the action of the crank and fly-wheel there is no other loss of power than such as is incidental to the common and well-understood causes of friction and atmospheric resistance.

16. Owing to such fallacious notions, much valuable inventive power has been wasted in attempts after the contrivance of what are called *rotatory steam engines.*

A rotatory steam engine is one by means of which a movement of continued rotation may be immediately given to a piston, or, in other words, by which the power of the steam can be immediately applied to a revolving wheel without the interposition of a piston, cylinder, beam, and crank. If such an application could be contrived without the various countervailing losses of power which have hitherto invariably attended such projects, it would certainly have some advantages; but it is not easy to see how such an object can be attained, and at all events, notwithstanding the expenditure of a vast amount of ingenuity and capital, it has never yet been effected.

17. Cases occur, as for instance in the locomotive and marine engine, in which a fly-wheel cannot conveniently be attached to the steam engine, and yet where uniformity of action is necessary. In such cases the object is usually attained by using two cylinders, which drive two cranks constructed on the same axle, but having such positions that when either is at its dead point, the other is at its point of maximum efficiency. Thus, while the efficiency of one crank increases, the other diminishes, and *vice versâ*, and the sum of their actions at all times is nearly the same.

SECTION XIII.—HOW THE STEAM ENGINE IS RENDERED A SELF-ACTING MACHINE.

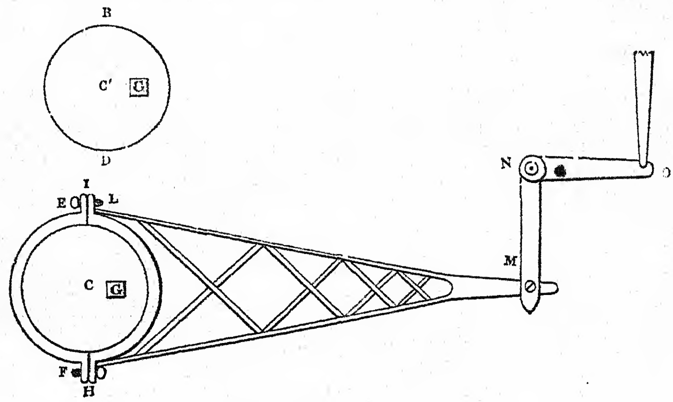
1. We have already stated that this is accomplished by making the engine open and close, at the proper times, the valves by which steam is admitted to and discharged from the cylinder. In the earlier engines this was accomplished by a *bar* or *rod* attached to the end of the working beam, and carried down parallel to the cylinder. On this bar were attached pins, so placed that as it ascended and descended they struck the handles or levers of the respective valves, and opened or closed them, as the case might be. This method is still used in some of the larger class of engines applied to the pumping of water. Where slides are used (as indeed is almost invariably the case), they are generally moved by an apparatus attached to the crank-shaft, called an *eccentric.*

2. This consists of a circular plate of metal B D, which is fixed upon a point G at some distance from the geometrical centre. Round this eccentric point it is made to

revolve, and in revolving it is evident that its geometrical centre, revolving round its centre of motion, will be thrown alternately to the right and to the left of such centre.

3. Now let us suppose this circular plate to be surrounded by a ring, within which it is capable of turning, but so that the ring shall not turn with it.

Then such ring will be thrown alternately to the left and to the right of the centre on which the eccentric plate is made to turn, and the length of its play, right and left, will be equal to twice the distance of the geometrical centre of such circular plate from the centre on which it turns. In the figure annexed, G is the centre on which the circular plate revolves; C is its geometrical centre; F I is the ring which embraces it, and within which it can turn. To this ring is attached a connecting rod



or frame, L M H. As the centre C is thrown alternately right and left of G by the revolution of the plate, the point M receives a horizontal motion, right and left, to a like extent.

This motion is transmitted by means of levers to the slides of the engine by obvious and well-known mechanical contrivances.

SECTION XIV.—HOW THE MECHANICAL EFFECT EXERTED BY THE PISTON IS ASCERTAINED.

1. Whatever be the circumstances under which the engine is worked, it will never happen that throughout the entire length of the stroke the pressure of steam on the piston will be exactly the same. Still less will it happen that the vacuum towards which the piston moves will be uniformly perfect.

The moment the exhausting valve is opened, the steam begins to rush from the cylinder to the condenser, but its condensation is not instantaneous. The first portion which mingles with the jet produces warm water, from whence steam is reproduced; and it is not until so much cold water has been mixed with the steam as will reduce its temperature considerably below 100°, that the vacuum in the cylinder will become practically perfect.

2. The more speedily this effect is produced, the more efficient will be the operation of the machine, but it never is produced until the piston has already made some portion of the stroke. The piston, therefore, begins to move against a vapour which offers some resistance more or less considerable, and the impelling power of the steam at the other side is to such extent neutralised. This resistance gradually diminishes,

and when the piston has made a certain portion of the stroke, it will have been reduced to its minimum amount.

It is evident, then, that this resistance must be ascertained and calculated before we can determine the mechanical efficiency of the piston.

3. But this is not all; the steam which impels the piston never acts throughout the stroke with uniform effect. When it acts expansively, being cut off at some determinate point of the stroke, we have already seen that it acts with an uniformly diminished pressure; but even where the expansive principle is not used, the steam is still cut off a little before the completion of the stroke.

4. There is still another point to be attended to. We are able by easy means to ascertain the pressure of steam in the boiler, but it would be a great mistake to assume that this must be the pressure of the steam in the cylinder. In passing from the boiler to the cylinder, the steam has to force its way through various passages, some of which are very contracted, and in so doing it suffers an effect which engineers express technically by the term *wire-drawn*. In fact, the steam loses somewhat of its density before it reaches the cylinder. If, then, we would know the real mechanical pressure on the piston, we must measure directly the pressure of the steam in the cylinder, and not derive our knowledge from its pressure in the boiler.

5. If we can at each successive point of the stroke ascertain the exact pressure of the steam which impels the piston, and also the pressure of the uncondensed vapour which resists it, we have only to subtract the one from the other to obtain the efficient pressure on the piston at the moment; and if we can do this successively throughout the entire stroke, we shall obtain the total mechanical efficiency of the engine.

6. A beautiful little instrument was, among the numerous results of his fertile genius, invented by Watt for this purpose, called an *indicator*. (See Section XXVII., title "*Watt's Indicator.*") It consists of a brass cylinder, something less than 2 inches in its internal diameter, and from 8 to 12 inches in length. It is bored with extreme accuracy, and a solid piston moves steam-tight in it with very little friction.

7. This cylinder is open at the top, and the piston-rod is kept precisely in its axis by passing through a ring placed near the top. A spiral spring surrounds the rod of the cylinder, and is attached at one end to the ring through which the rod plays, and at the other end to the piston. When no force acts on the piston, and this spring is therefore neither extended nor compressed, the piston stands at the centre of the length of the cylinder; when any force presses the piston upwards, the spring is compressed, and the piston rises; and when any force presses the piston downwards, the spring is extended, and the piston descends.

From the known mechanical qualities of a spring of this species, it follows that the space through which the piston rises or falls always indicates the force by which it is urged.

At the top of the piston-rod, and at a right angle with it, is attached a pencil, which plays upon a card properly placed, and traces upon it a line according to the ascent or descent of the piston.

While the piston of the engine descends, the card is moved horizontally against the pencil through a certain space; and while it ascends, it is moved back again through the same space: by this combination of movements a geometrical figure is traced upon the card, the breadth of which, measured vertically, represents for each point of the stroke the effective pressure, and the entire area of such figure represents the total effect.

When the steam acts against the piston of the indicator, the space through which that piston ascends represents the excess of the pressure of the steam above that of

the atmosphere ; and when it descends by reason of the vacuum, the space through which it descends represents the excess of the pressure of the atmosphere above the pressure of the uncondensed vapour : consequently, the sum of these two spaces will represent the excess of the pressure of the steam which impels the piston of the engine above the pressure of the uncondensed vapour which resists it ; and this being taken for each successive point of the stroke, it follows that the entire area of the figure will represent the effective action of the piston of the engine. This will be more clearly understood by referring to the figures, with their explanations, in Section XXVII.

8. The chief value, however, of this contrivance consisted more in its indication of the action of the condenser than as affording a direct measure of the effective action of the machine. It showed at once, and in a manner quite unequivocal, whether the condenser was doing its duty, and whether the condensation was sufficiently prompt. The moment the exhaust valve is opened, the piston of the indicator ought suddenly to drop ; and although it will sink lower while the stroke proceeds, the chief motion should be instantaneous. When the condensation is not prompt, then the piston falls more slowly, and shows either that there is not enough water injected, or that some other impediment interferes with the due performance of the condenser.

9. Dynamometers are occasionally used to measure the force exerted by engines. Some of these, as Morin's dynamometer, record by diagram on paper the work done in dragging a load or driving a shaft.

For testing the power of the smaller class of engines, a very useful and convenient apparatus consists of a pulley mounted in suitable framework, and driven by the engine.

A flexible break is applied round a considerable portion of the circumference of this pulley. Weights are hung on the break-strap to produce friction. These are adjusted until the friction of the break becomes equal to the power expended in turning the pulley at any assigned uniform velocity. In that case the weight is kept in equilibrium, neither rising nor falling, and thus measures the work done by the pulley : that weight being equal to a weight of the same magnitude lifted vertically through the space described by the circumference of the pulley.

SECTION XV.—HOW THE HEAT IS PRODUCED BY WHICH STEAM IS MADE.

1. The cylinder, piston, beam, connecting rod, crank, and fly-wheel, are, like all other pieces of mechanism, mere contrivances by which mechanical force is transmitted and modified. There is nothing in them by which mechanical force can be produced. Once at rest, at rest they would for ever remain, unless some motive power were applied to them.

2. This moving power, as we have already described, is derived from the physical phenomena which are exhibited when water is converted into steam ; but even the water in this case cannot properly be regarded as any more than an instrument by which the mechanical agency of the heat is developed. Heat, then, is the prolific parent of the vast powers of the steam engine, and it is of the utmost practical importance to comprehend fully how this heat can be produced and applied with the greatest economy and efficiency.

3. This will lead us to the consideration of those properties of combustibles on which the production of heat depends, and the construction of the furnaces and boilers by means of which its application and transmission are effected.

4. The combustibles universally used in the furnaces of steam engines are either pit-coal, coke, or wood. The former are used almost invariably in Europe ; the latter

is used in America, except in particular districts where coal is advantageously attainable.

5. The constituents of coal are chiefly carbon and a gas called hydrogen, combined occasionally with a small proportion of sulphur and incombustible matter.

6. In the process of combustion, the carbon, the hydrogen, and the sulphur combine with the oxygen gas, which is a constituent of the atmosphere, and other products are formed. In this combination a quantity of heat is developed. The incombustible constituents drop from the grate, and are left in the ash-pit. The goodness of coal depends in some degree on the small proportion of incombustible matter which it contains.

7. The proportion of carbon contained in coal varies ; in good coal it is seldom less than 75 per cent. of the whole, sometimes considerably more.

8. Hydrogen cannot be said to enter as a constituent of coal in its pure and simple form : it is always combined with a portion of carbon, and is the gas called *carburetted hydrogen*, being that which is commonly used for the purposes of illumination. This gas may be expelled from coal by exposing the latter to heat, by which means the gas expanding, escapes from the coal, and may, if required, be collected in proper reservoirs. This process, applied to the coal, is called coking ; and it is in this manner that the gas is collected in gas-works for the purposes of illumination.

9. The proportion of carburetted hydrogen, the element which produces flame, varies in different sorts of coal. The more bituminous sorts, such as the coking coals of Northumberland and Durham, generally have a considerable proportion ; the heavy coal called stone-coal, obtained in some of the coal-fields of Wales, Pennsylvania, and elsewhere, has very little.

Carbon burns without flame, the product of its perfect combustion being the gas called *carbonic acid*, which escapes from the fuel in a very heated state.

10. These are the general effects of combustion ; but for the practical purposes of art something more must be learned. We must ascertain with some degree of precision the quantitative proportions in which the various elements concerned in the phenomena are present.

11. To begin, then, with the chief ingredient of all combustibles,—carbon,—

This substance, when heated to a temperature of 700° or 800°, equal to that of red-hot iron, will enter into chemical combination with the gas called oxygen ; the result of this combination will be another gas called carbonic acid. In forming this combination a large quantity of heat, previously latent in the carbon and the oxygen, is rendered sensible, and is developed in two ways : 1st, in rendering the remainder of the carbon incandescent, or white-hot ; and, 2ndly, in raising the temperature of the carbonic acid which has been produced to a very high point.

12. From the luminous or incandescent carbon the heat escapes by radiation, according to the same principles and laws that govern the radiation of light. That portion of it which is carried off by the carbonic acid may be taken from such gas by placing in contact with it any surface which is a good conductor o heat, such as metal ; the heat of the gas will be imparted to the metal until the temperature of the metal and the gas be equalised.

13. But it is necessary to know the *quantity* of oxygen gas which is requisite to combine with the carbon.

It is found that a pound of pure carbon will enter into combination with 31 cubic feet of oxygen at the ordinary temperature and pressure of the air, the result of the combination being 31 cubic feet of carbonic acid, this being supposed to be reduced to the same temperature and pressure. But as the temperature of the carbonic acid,

at the moment of combination, is very much elevated, it will then have an enlarged volume.

14. Common combustion, however, is maintained not by an atmosphere of pure oxygen, but by that of the common air.

15. Common air is a mixture of oxygen and azote, in the proportion, by measure, of 1 to 4,—5 cubic feet of common atmospheric air containing but 1 cubic foot of oxygen. To obtain 31 cubic feet of oxygen, therefore, we must necessarily have 5 times 31 or 155 cubic feet of common air.

16. Supposing, then (which is, however, in practice, not the case), all the oxygen contained in the atmospheric air supplied to the fuel in combustion to enter into combination with such fuel, it would be necessary to supply 155 cubic feet of atmospheric air for every pound of carbon consumed.

17. The result of this combination would be the production of 31 cubic feet of carbonic acid, formed by the combination of the oxygen of the atmosphere with the carbon, and 124 cubic feet of azote, which would be mixed with the carbonic acid so produced. This volume of mixed gases would escape from the fuel at a very high temperature, and would in this state pass into the chimney.

18. Hydrogen gas combines with 8 times its own weight of oxygen, and the result of the combination is water, or, more properly speaking, steam ; for it is rendered into the vaporous form by the great heat developed in the combustion.

19. We have stated that a small proportion of sulphur is present in most sorts of coal. In burning, this produces sulphurous gas. It is inefficient as to its heating power, and insignificant in its quantity, but most injurious in its effects on boilers. Coal, therefore, having much of this element should be avoided in steam boilers.

20. To maintain the fuel in combustion, it is then evident that it must be continually supplied with atmospheric air. The rate of this supply will depend on the rapidity of the combustion which is required, and the quantity and quality of the fuel. The fuel is spread on a grate, between the bars of which the air which sustains the combustion is admitted. In passing through the fuel, the air enters into combination with it, and the gases resulting from the combustion, including uncombined oxygen and the azote of the atmospheric air, which last plays no part whatever in the combustion, issue together into the upper part of the furnace, all having a very high temperature : these proceed to the chimney, which they soon fill with a column of heated air, the buoyancy of which makes it ascend into the atmosphere, and the vacuum it leaves behind it draws a fresh portion of air through the grate bars, and so the combustion is continued.

21. The azote, which forms so large a constituent of atmospheric air, has qualities in relation to combustion merely of a negative kind ; it does not either check or stimulate it. Thus, as a supporter of combustion, the atmosphere may be considered as diluted oxygen, the azote having the same effect on the particles of the oxygen as water would have upon a strong spirit mixed with it.

22. In what has been just explained, the calculations are based upon the supposition that every particle of oxygen contained in the atmospheric air, urged through the burning fuel, enters into combination with it. Now this is not and cannot be the case, even in the most approximative sense ; and therefore, to complete the combustion of the fuel, a much greater quantity than 155 cubic feet of atmospheric air for a pound of carbon consumed must be drawn through the fire. The exact quantity which is necessary is not capable of calculation, for it depends on circumstances which vary with the form and structure of the grate and the mode of working the furnace.

23. It will be understood that when the fuel is laid in a stratum more or less thick upon the grate, and when rapid currents of air are ascending through its interstices,

a quantity of the fuel, always existing in the state of powder or small dust, will be carried upwards by the current, unburned.

24. Besides this, as the heat expels the hydrogen gas from the interior of the coal, minute particles of the coal itself escape with the current, and rise above the fuel. Much of this is also unburned, or, to speak scientifically, uncombined with oxygen. It is this minute powder or dust, uncombined with oxygen, that forms what is called smoke. The gaseous products of combustion, properly so called, have not the cloudy and opaque appearance which characterises smoke. This smoke, then, is unconsumed fuel, and to whatever extent it is produced, it escapes into the chimney, and is a source of waste. It is clear, then, on the grounds of economy, independently of sanitary considerations relating to the neighbourhood of the engine, that the quantity of fuel, more or less, thus escaping, should be arrested and burned before it reaches the chimney.

25. Various methods have been adopted in furnaces for accomplishing this object. Such arrangements are denominated smoke-consuming furnaces; but very simple and obvious arrangements may be adopted in the mode of feeding common furnaces, which will have the effect of consuming the smoke.

26. If the heated gases proceeding from the fuel passed directly to the chimney, they would carry with them a much greater quantity of heat than would be necessary to maintain the draft, and thus a portion of the heat developed by the fuel would be lost. To prevent this, the heated air and flame which escape from the fuel, instead of passing directly to the chimney, are conducted through passages of greater or less length in contact with the boiler, and made to impart a portion of their heat to the water before they enter the chimney. These passages are called *flues*, and are very variously constructed, according to the form, magnitude, and application of the boiler.

27. In some boilers the flues are made to wind round them, the external part of the flues being made of brickwork, which, being a bad conductor of heat, takes but little from the heated air and flame.

28. The shape and proportions of *boilers* are so adapted as to accommodate them to such systems of flues. The great object is to adopt such arrangements as shall secure the transmission to the water of all the heat developed in the combustion of the fuel, except such portion of it as may be necessary to maintain a sufficient draft in the chimney.

29. The boilers most commonly used are cylindrical. Cylindrical boilers are generally long in proportion to their diameter, and their ends are often spherical. This shape is highly conducive to strength, but in some cases their ends are made flat.

30. In cylindrical boilers the furnace is generally placed within the boiler, in a large tube which extends from end to end of it. In one end of this tube is placed the grate, and the remainder of it forms a flue. By this arrangement, all the heat which radiates from the fire, and even from the ash-pit, acting upon this internal tube, is communicated to the water. The heated air, traversing the tube to the remote end, imparts its heat to the water by this means. Flues circulate round the outside in the same manner as in the waggon boiler.

31. Internal flues have the advantage of imparting more of the heat to the water.

32. In some forms of boilers, the grate being constructed at one end, the flame and heated air, instead of passing through a single internal flue traversing the length of the boiler, are distributed among three or more similar tubular flues.

33. This subdivision of flues by the multiplication of the number of tubes, and the diminution of their magnitude, is carried to an extreme in locomotive boilers, in

which from 100 to 200 tubes, not more than 2 inches diameter, traverse the length of the boiler, and divide the flame and heated air into a multiplicity of small threads, so as to enable the water to deprive them of their heat.

34. With these a system of returning flues becomes unnecessary, the reduction of the temperature being completely effected in traversing the boiler once.

35. In some arrangements the flame and heated air passing from the furnace enter number of narrow upright cells, placed parallel to each other, and traversing the length of the boiler: arriving at the remote end, another tier of cells, at a superior elevation, is provided, by which they return. This is most commonly the expedient adopted in marine boilers.

36. The multiplicity and complexity of flues, whatever be their form, have the double disadvantage of increasing the cost of the boiler and diminishing its strength. They are therefore only resorted to in cases in which circumstances exclude a great magnitude and weight of boiler, such as in locomotive and marine engines. In the boilers used in land engines, the requisite evaporating power can be obtained with more simple expedients, by merely augmenting the bulk of the boiler.

37. The two great objects which are to be attained are—rapidity of evaporation and economy of fuel.

38. The evaporating power of the boiler will depend (other things being the same) upon the extent of surface which it exposes to the action of the fire, the flame, and the heated air. This surface is technically divided into *fire surface* and *flue surface.*

39. By fire surface is meant all that surface of the boiler upon which the radiant heat of the furnace acts.

40. The flue surface, as the words import, is that portion of the surface of the boiler in contact with which the flame and heated air proceeding from the fire pass before they issue into the chimney. This surface is usually of considerable length, in order that the flame and heated air may be detained in contact with the boiler until they have been reduced to a temperature not greater than is necessary for the draft.

41. Whatever be the length and arrangement of the flues, it is indispensably necessary they should always be below the level of the water in the boiler, for otherwise the heat would be imparted to the metal of the boiler without being transmitted to the water. Steam is a sluggish recipient of heat, and metal in contact with it might become red-hot while the steam itself will remain at a comparatively low temperature.

This would accordingly be the case if the fire or flame acted upon any part of the metal of the boiler which has not water within it.

42. In the economy of steam power, an object of capital importance is to protect the machinery from every cause by which heat can be consumed in any other way than in converting water into steam. A great variety of expedients have accordingly been adopted for this purpose, differing from each other in their effects, according to the circumstances in which the machinery is worked.

43. A boiler being a mass of metal of extensive magnitude, raised to a very elevated temperature, and which is naturally a good radiator of heat, a considerable quantity of heat would be lost by the mere radiation from its surface. The obvious remedy for this is to surround it by some material which is a bad conductor of heat.

44. One of the most effectual substances for this purpose is common sawdust: this is accordingly applied with great effect in cases which do not exclude its use.

45. The boiler and its appendages are surrounded by a thick casing, stuffed with sawdust, and so completely does this expedient answer the purpose, that the boiler-

room of a Cornish engine, where this arrangement is applied, is often the coolest place that can be found.

46. In marine and other engines, a coating of patent felt is often used with advantage : hemp and other fibrous and woollen substances may be resorted to.

47. Locomotive boilers are cased in wood, which is a tolerable non-conductor. The cylinders of large stationary engines are also frequently cased in wood. The steam pipes and other parts of the machinery containing steam are wrapped with tow or other similar substances.

48. By these means the loss of heat by radiation may be reduced almost to nothing.

49. Where fuel is used which burns with little or no flame, such as stone-coal or coke, the chief effect is produced by the radiant heat, and a comparatively small effect by the heated air. In such cases the fire surface should bear a large proportion to the flue surface. In all cases the fire surface, being more active in proportion to its extent than the flue surface, is more liable to wear by intense heating. It may be said, that as the surface of the metal cannot rise to a higher temperature than that of the water within, and as the entire mass of the water within must be maintained at an uniform temperature, the fire surface cannot rise above the general temperature of the mass. This would be true if the boilers and furnaces were worked by a moderate system of combustion, the fuel being consumed very gradually, and the heat developed slowly, so that a fierce action should not take place on any part of the boiler. Such is the case, for example, in the boilers and furnaces of the Cornish engines, where space is a matter of little importance, and the economy of fuel pushed to its extreme limit ; but in other cases these advantages must be sacrificed, and a combustion so intense maintained in the furnaces that the fire surface becomes heated to a higher temperature than the water in contact with it, and to a much higher temperature than the flue surface. The formation of steam in contact with the fire surface is so rapid that its bubbles do not escape to the surface quick enough to keep the metal in continual contact with water.

50. The metal, therefore, is momentarily out of contact with water, and has a tendency to become overheated.

51. It is true that upon the escape of the steam bubbles just formed the liquid will again wash the metal and lower its temperature, but still this effect is such (in the case, for example, of locomotive engines and sometimes of marine engines), that the fire surface is exposed to much more rapid wear by temperature than the flue surface.

SECTION XVI.—HOW THE DRAFT THROUGH THE FURNACE OF A STEAM ENGINE IS MAINTAINED.

1. The most common method of effecting this is by the ordinary expedient of a chimney.

2. When the products of combustion are allowed to flow through a chimney of sufficient height, the vertical column of heated air thus formed has a certain buoyancy or tendency to ascend into the atmosphere, proportional to the difference between its weight and the weight of an equal column of common air. This difference will be so much the greater as the column has greater magnitude and height, provided only that every part of it shall be, bulk for bulk, lighter than air. Hence obviously follows the necessity of a chimney in creating a draft, whether through the furnace of a steam engine or in any ordinary manner.

3. In stationary engines, as used in the arts and manufactures, chimneys of any desired magnitude can generally be attached to the engine. It is not necessary that

the chimney should be immediately over or contiguous to the furnace; it may be placed at a considerable distance from it, provided only it be connected with it by the proper air passages. This is often a matter of convenience in factories, and we accordingly see the chimney frequently erected at a considerable distance from the boilers and furnaces.

4. But in numerous applications of the steam engine it is not practicable to use chimneys of such elevation, or so placed, and in some cases the tube provided for the escape of the products of combustion must necessarily be so short as to afford no draft of appropriate amount.

5. Such is the case, for example, in locomotive engines: in marine engines this is to some extent also true,—the chimney must be comparatively short.

6. When sufficient length of chimney is not admissible, we are compelled either to throw in the gases of combustion at a very high temperature, so as to make up for want of height in the column, or to adopt some other expedient for creating a draft.

7. A wheel is sometimes placed in the flues where they enter the chimney, by the revolution of which the gases are driven up the chimney with a force proportional to the velocity with which the wheel revolves. This expedient is similar to a sort of bellows commonly used for domestic purposes, and is called a *fanner*, and sometimes a *blower*. A portion of the power of the engine is borrowed to keep this wheel in motion. In this way an upward current is maintained in the chimney of any required power, and the necessary draft sustained through the furnace.

8. Another expedient is used in locomotive engines, and may always be resorted to where steam of high pressure is used. This consists of a *jet*, or, as it is technically called, a *blast-pipe*, which is placed at the base of the chimney, and presented upwards. A portion of the steam received from the engine is allowed to escape by puffs, or even in a continued stream, through this pipe, and being directed up the chimney, creates the necessary draft.

SECTION XVII.—HOW THE MECHANICAL VIRTUE OF FUEL IS ESTIMATED AND EXPRESSED.

1. In explaining the mechanical effects of steam, it has been already shown that whatever be the purpose to which the force of a steam engine is applied, its effect may always be represented by a certain weight raised a certain height.

2. Whether an engine be employed to drive a mill-wheel, to propel a ship, or to draw a carriage, the tension or resistance to be encountered at the working point may be universally represented by an equivalent weight.

3. Thus it is easily understood, if a locomotive engine draws a train of carriages, that the tension of the chain which connects the engine with the train will be the same as if the same chain, in a vertical position, had a certain weight suspended to it; and the same will be true, whatever be the nature of the resistance to the moving power, or the manner in which this moving power may be applied.

4. It has been usual also to express the mechanical efficacy by the number of pounds raised one foot; for whatever be the resistance, and whatever be the space through which the moving power acts upon it, the effect can always be reduced, as has been already explained, to an equivalent number of pounds raised one foot.

5. The mechanical virtue of coals, thus explained and applied to a steam engine, has been technically called the *duty of the fuel*. Thus a bushel of coals consumed in the furnace of an engine will enable such engine to exert at the working point a mechanical effect equivalent to a certain number of pounds raised one foot high: this effect is the duty of the fuel, or, as is sometimes said, the duty of the engine.

6. The duty of the engine is therefore not the entire mechanical effect developed by

the fuel in producing evaporation, for a portion of the mechanical power of the steam evolved in the boiler, and in some cases a very large portion of it, is expended in moving the machinery of the engine itself: all such portion is intercepted therefore between the furnace and the working point. The duty, properly speaking, is the net mechanical force developed by the steam, or such portion only as is available for the work to which the engine is applied.

7. The duty of engines varies within very wide limits, according to the purpose to which they are applied. In this respect engines may be reduced to three classes:— 1st, Such as are used in the mining districts of Cornwall; 2ndly, The stationary engines used in the manufactories generally, in which class may also be included marine engines; 3rdly, Locomotive engines on railways.

8. In the Cornish engines, where very accurate observations are made on the mechanical effect produced, and on the economy of fuel, it has been found, in some cases, that by the combustion of a bushel of coals an effect has been produced by the engine equivalent to 125 millions of pounds, or, what is the same, 62,000 tons raised a foot high. This, however, is not to be understood as an average result. In producing it, the utmost care was taken to guard against every source of waste of power.

9. The more common duty obtained from a well-managed engine used in the mining districts has been from 80 to 90 millions of pounds, or at the rate of one million of pounds raised one foot for every pound of coal consumed, — a result remarkable enough in itself, and easily remembered.

10. In the ordinary stationary engines belonging to the second class, where the same scrupulous attention to economy cannot be or is not paid, the duty, according to the commonly received estimate, is, in round numbers, about 20 millions of pounds for a bushel of coal, being four times less than that of the good Cornish engines, and six times less than the duty which has in certain cases been obtained.

11. In the locomotive engines worked on railways the economy of fuel is little if at all less than that of factory engines.

12. The great economy obtained in the engines used in Cornwall is the result of a variety of contrivances, some of which, such as the protection of the machinery from radiation, have been already mentioned. The boilers are constructed of extraordinary magnitude, in proportion to the power expected from them; the furnace is of proportionate size; the combustion is slow; the heating surface is very extensive, and the intensity of heat upon it very slight; the flues are of great length, and the heated air is not permitted to escape until the last available portion of heat has been extracted from it; the fuel is managed in the furnaces with the most extreme care, the combustion being perfect. Added to all this, the steam is used at a pressure of from 35 to 50 pounds per square inch above the pressure of the atmosphere, and the expansive principle extensively applied.

13. In giving these last estimates of the duty of fuel in the engines used in the manufactures generally, it is right to observe, that owing partly to the difficulty of ascertaining the actual mechanical effect produced, and partly to the negligence of proprietors of engines, the estimates of duty are of the most loose and inaccurate description. When an engine is applied, as is generally the case in Cornwall, directly to the elevation of water or other heavy matter, it is easy to observe the mechanical effect it produces; but when an engine is applied to give motion to the works of a factory, to drive spinning-frames, power-looms, or printing-presses, it is not so easy a matter to reduce the effect it produces to an equivalent weight raised a given height. In the case of locomotive engines the same difficulty ought not to exist; yet it is surprising that for a considerable period grave errors prevailed respecting the real mechanical effect produced by these machines. It was, for example, long assumed as

a maxim, that the resistance offered by a given train of carriages to a locomotive engine was independent of the speed, or, in other words, the same at all speeds. This error was not brought to light until the year 1838, when it was demonstrated, by a series of experiments conducted by me, that the resistance was augmented in a very high ratio with the speed.

SECTION XVIII.—HOW THE POWER OF AN ENGINE IS ESTIMATED AND EXPRESSED, AS DISTINGUISHED FROM ITS DUTY.

1. The duty, as we have seen, is the practical effect produced by a given weight of coal, without reference to time. Thus, whether a bushel of coal raises 20 millions of pounds a foot in one hour or in ten hours, the duty of the engine is exactly the same. But the *power* of the engine is quite different.

2. The *power* of the engine is estimated by the mechanical effect it is capable of producing *in a given time.*

When steam engines were first brought into use, the work to which they were applied had been previously done by horses who worked the mills. It was convenient, therefore, and indeed indispensable, to express the mechanical capabilities of these machines by declaring the number of horses which one of them would supersede ; and hence the term, now so general, *horse-power*, came into use. At first this expression had but a vague signification, and was understood by the manufacturers and capitalists who intended to employ the steam engine in the literal sense of the actual number of horses whose expense would be saved to them by it. But after the engine had completely superseded horses in the arts and manufactures, and it became necessary to express its effects with greater precision, instead of abandoning the term horse-power, an arbitrary signification was given to it by Watt, which it has since retained. The word horse-power, then, as applied to the steam engine, means the capability of the engine to produce a mechanical effect per minute equivalent to 33,000 pounds raised one foot.

3. Thus an engine of 10 horse-power means one which in working is capable of producing a mechanical effect per minute of 330,000 pounds raised one foot, or an effect per hour equivalent to 20 millions of pounds, very nearly, raised one foot.

4. When a steam engine is declared to be of such or such a horse-power, the expression must be understood in a qualified sense. Thus it is assumed that the furnace is worked in a certain average manner, and that a proportional evaporation takes place in the boiler. An engine whose nominal power is that of 100 horses may, by urging the furnace in an extraordinary manner, be made to produce an effect much greater than that of its nominal power ; or, on the other hand, by keeping the furnace low, it may be, and frequently is, worked considerably under its nominal power. In the same engine, consequently, the power may vary through a wide range according to the pressure at which the steam is worked, and to the rapidity at which it is generated.

SECTION XIX.—THE DIMENSIONS OF THE BOILER AND FURNACE NECESSARY FOR AN ENGINE OF GIVEN POWER.

1. The technical rules adopted by engineers for the proportion of engines corresponding to any required power, are generally understood as applicable only to the second class of engines enumerated already, namely, those generally used in the manufactories and in steam navigation.

2. The Cornish engines on the one hand, and locomotive engines on the other, are exceptional extremes, each being worked in a manner peculiar to itself. In the one, much larger dimensions are allowed for the production of a given power, the action

of the furnaces being of low intensity; while in the other, the dimensions producing a given power are much smaller, and the consequent action of the furnaces much more intense.

What we shall therefore state here will be understood to have reference to the second class of engines above mentioned.

3. In calculating the mechanical force developed in the evaporation of water, we have seen that one cubic inch of water, converted into steam, produces a mechanical force sufficient to raise a ton weight a foot high. It would therefore follow that to raise 2 millions of pounds a foot high, would require the evaporation of 1000 cubic inches of water. But this calculation refers to the entire mechanical force developed in the evaporation. A portion of this force is, however, expended in moving the engine itself, and is wasted in various ways before it reaches the working point; and it is customary for engine-makers to allow for this from 35 to 45 per cent. of the entire mechanical force developed in the evaporation. Now since there are 1728 cubic inches in a cubic foot, it follows that, by such an allowance for waste of power, the net effect of a cubic foot of water evaporated per hour would be one nominal horse-power.

4. Such is the general usage of boiler-makers, but it would be most erroneous to assume that this usage is based upon even a loose calculation; there can be no doubt that the power expended in waste and uncondensed steam, and in moving the engine in any tolerably managed machine, must be considerably less than this. The error, however, lies on the safe side; it is better to have superfluous boiler-power than a stint of steam. A boiler having more evaporating power than is needed, can always be worked as much under its power as may be desired; but when an engineer is obliged to push a boiler above its legitimate power, both waste and danger ensue. It must not therefore be assumed, as has been done by some writers, that engine-makers adopt these rules from ignorance. Although they do not in general seek for an accurate knowledge of the amount of power expended in moving the engine and in waste steam, they are nevertheless fully aware that the allowance they make is greater than its amount; and in the absence of such exact knowledge, it is clear they are right in adopting an excessive estimate.

5. From what has been stated, therefore, it follows that for every horse-power which the engine is expected to exert, a power of evaporating a cubic foot of water per hour is provided in the boiler.

6. When the term horse-power is applied, therefore, to boilers, in reference to their capability of evaporation, it is to be understood as indicating the evaporation at the rate of a cubic foot of water per hour: thus, by a boiler of 50 horse-power is to be understood a boiler capable of evaporating 50 cubic feet of water per hour, the furnaces being worked in the ordinary way.

7. The magnitude of the grate and the extent of heating surface necessary to produce a given rate of evaporation vary more or less in different engines, and according to the practice of different engineers; but still, in common engines used in the arts and manufactures, there are average standards which it is useful to know.

8. Thus it is generally agreed that the dimensions of the grate necessary for a boiler of a certain power should be regulated by allowing a square foot of grate surface for every horse power in the boiler. Thus it follows, that as much fuel is consumed per hour upon a square foot of the surface of the grate as is necessary and sufficient to evaporate a cubic foot of water.

9. The dimensions of the surface of the boiler exposed to the action of heat, whether by radiation or by the contact of heated air in the flues, is generally estimated at the rate of 15 square feet for a horse-power. Thus a boiler of 50 horse-power would require a heating surface of 750 square feet.

10. These are not only average standards from which individual boilers and furnaces of the class we more particularly refer to vary more or less considerably, but they are altogether inapplicable to the two extreme classes of boilers,—the Cornish on the one hand, and the locomotive on the other.

11. In the Cornish boilers a slow combustion is maintained on the grates, and although the fuel is placed upon them in a thicker layer, the intensity of the heat from a given surface is considerably less than in the ordinary boilers. Accordingly, for a given rate of evaporation, at least double the extent of grate surface is allowed. We find, therefore, that two square feet are given for every cubic foot of water per hour to be evaporated.

12. In like manner, as in these boilers the heat acts with less intensity on a given surface of the boiler, a proportionally greater heating surface is necessary to produce a given rate of evaporation. In these cases a still greater departure from the common boiler is necessary; and instead of 15 square feet being allowed for a cubic foot of water per hour evaporated, we find 4 and 5 times this surface given.

13. The flame and heated air are also made to traverse a much greater length of flues before they enter the chimney.

14. The locomotive boiler is in the other extreme. Instead of one square foot of grate surface evaporating one cubic foot of water per hour, it usually evaporates 10 cubic feet. As the heat developed in a given time may be taken as nearly proportional to the water evaporated, it follows that the calorific action of a square foot of the grate of the locomotive is 10 times that of a square foot of the grate of a common stationary engine, and 20 times that of a Cornish engine.

15. The intensity of the combustion maintained in the furnaces of locomotive engines may be thus in some measure conceived.

The splendour of the burning fuel in these furnaces is sometimes so intense that it impresses the eye with the same pain as is sustained in looking at the sun.

16. The Cornish boilers, which differ so extremely in their mode of operation and effects from the locomotives, resemble them nevertheless very closely in their form. Both are cylindrical, and the flues in both consist of metal tubes, traversing the length of the boiler. In the Cornish boilers the tubes are of iron, and of considerable diameter. In the locomotive boilers they are usually of brass, and very small in diameter.

17. The diameter of the Cornish boilers is usually about $\frac{1}{6}$th of their length. Where great power is required, it is found more convenient to use two or more boilers than one of larger dimensions. A common proportion for these boilers is from 36 to 40 feet of length, and from 6 to 7 feet in diameter. The locomotive boilers are usually from 8 to 10 feet long, and from $3\frac{1}{2}$ to $4\frac{1}{2}$ feet in diameter.

18. The common published reports of the consumption of fuel are usually given by expressing the weight of coal consumed per hour per horse-power; but unless it be ascertained that the real working power of the engine and the consumption of fuel are equal to and do not exceed its nominal power, such reports lead to erroneous conclusions. The common allowance of fuel for stationary engines and marine engines, when working to their full power, is 10 lbs. per horse-power per hour. The consumption, however, is undoubtedly less than this when the engines are properly constructed and carefully worked: 7 and 8 lbs. per horse-power is a very common consumption for well-managed engines. In the Cornish and other engines worked expansively, the consumption has been reduced as low as 3 to 4 lbs. per horse-power per hour.

SECTION XX.—WHAT DIMENSIONS OF THE CYLINDER AND OTHER MACHINERY ARE REQUISITE FOR A GIVEN POWER OF ENGINE.

1. Nothing can be more vague, uncertain, and arbitrary, than the older rules adopted by engineers in reference to this problem. It may be truly stated that every engine-maker has his own standards, to which he attaches invariably as much infallibility as if this mechanical problem were capable of as certain and demonstrative solution as a problem in common geometry.

2. It will be obvious, on the slightest consideration, that the magnitude of the cylinder and piston necessary to produce a given working power must depend on the pressure of the steam after it enters the cylinder and the velocity with which the piston is driven, the degree of perfection of the vacuum on the other side of the piston, and the extent to which the expansive principle is introduced. In general, however, it has been the practice to apply the calculation to low-pressure engines, that is to say, to those in which the steam, after it enters the cylinder, has not a pressure exceeding the atmosphere by more than 7 lbs. per square inch, and in which the piston is supposed to move at the average rate of 200 feet per minute. These conditions being assumed, and a good vacuum being sustained in the condenser, 22 square inches of the piston are allowed for every nominal horse-power of the engine.

3. Where these rules are observed, the nominal power of an engine may always be obtained by dividing the number of square inches in the surface of the piston by 22; or, which is the same, by dividing the square of the diameter of the piston, expressed in inches, by 28.

4. Again, if it be required to find the magnitude of the piston necessary for an engine of a given power, it is only necessary to multiply the number expressing the power by 28, and the square root of the product will be the diameter of the piston.

5. It must be carefully observed, however, that such rules are only applicable so long as the piston moves with the above velocity, and is urged by low-pressure steam at the above rate.

6. Indeed, it may be observed generally that the mode of expressing the mechanical capabilities of engines by horse-power frequently leads to most erroneous conclusions, and it has lately been accordingly much discontinued among engineers and scientific men. In locomotive engines it is not applied at all; nor, indeed, in the Cornish engines.

7. The proportion of the diameter to the stroke of the cylinder, as its length is called, varies very much according to the purposes to which the engine is applied. In marine engines, for example, where the cylinder has a vertical position and the engine is stinted in height, the stroke very little exceeds the diameter. In stationary land engines the proportion of the diameter to the stroke is frequently that of 1 to 2.

8. The dimensions of the air-pump, condenser, and other parts of the engine, bear a certain proportion to those of the cylinder, which are but little departed from by engine-makers.

9. Thus, the air-pump has usually half the stroke and half the area of the piston, and consequently its capacity is a quarter of that of the cylinder; nevertheless, some engineers maintain that a larger proportion of air-pump augments the efficiency of the machine.

SECTION XXI.—HOW THE INTERNAL CONDITION OF THE BOILER AND ENGINE IS RENDERED EXTERNALLY MANIFEST.

1. To enable the engine-man to maintain the boiler and machinery in a state of efficient operation, it is necessary that he should be at all times informed of their internal condition. A class of contrivances for indicating this has therefore exercised

the invention of those to whom we are indebted for the improvement of this department of mechanical art.

2. One of the most obvious circumstances attending the internal condition of the boiler, which it is necessary that the engine-man should at all times know, is the quantity of water in it. If the level of the water get below the flues, the boiler incurs the danger of becoming red-hot, and bursting; if the level of the water be too high, the steam room in the boiler becomes insufficient, and the spray of the boiling water, mingled with the steam, passes through the steam-pipes into the cylinder, producing a waste of heat, and other inconveniences: this effect is called *priming*. The level of the water in the boiler should therefore always be known.

3. The earliest and most simple contrivance for indicating this is the *gauge-cocks:* these cocks are two common stop-cocks, screwed or cemented into the boiler, one above the point at which the level of the water ought to stand, and the other below it. When the water is at the proper level, steam should issue on opening the one, and water on opening the other. If water issue from the upper cock, the boiler is too full; and if steam issue from the lower cock, the boiler is too empty. So long as steam issues from the upper and water from the lower, the level of the water is at its right point.

4. In boilers maintained in a very violent ebullition, where a highly intense furnace is used, the agitation near the surface renders the indication of the gauge-cocks sometimes uncertain, and another contrivance is either substituted for them, or used in connection with them.

5. If it were possible to have a glass boiler, the level of the water would always be visible; but instead of a boiler all glass, we may have a strong glass plate inserted into the side or end of the boiler at the level at which the water ought to stand, and through this plate the surface of the water might be seen; but the great agitation of the water in ebullition would render this observation uncertain; the object is therefore accomplished by the glass *water gauge* (see Section xxvii. title '*Glass Water Gauge*'), which is a strong glass tube placed in a vertical position outside the boiler, communicating at the top and bottom by metal tubes with the interior. The water in the boiler enters the lower end of this tube, and the steam enters the upper end; and, by the common principles of hydrostatics, the pressure of the steam in the tube and in the boiler being the same, the water in the tube will stand at the same level as the water in the boiler.

6. To guard against the effects of the accidental fracture of this tube, stop-cocks are usually placed between the ends of it and the boiler, by which the communication between it and the boiler is cut off at pleasure. When the engine-man desires to ascertain the level of the water in the boiler, he opens both the stop-cocks, but at other times it is more prudent to keep them closed.

7. This expedient has the advantage over the gauge-cocks, inasmuch as it indicates the exact level of the water.

8. Another contrivance used for this purpose consists in a *float*, formed of a hollow casing of metal; to this is attached a rod which passes through the top of the boiler.

As the level of the water rises or falls in the boiler, this float rises or falls with it, and the rod is pushed upwards or drawn downwards, as the case may be. An index of any kind may be attached to this rod, which should play upon a divided scale indicating the position of the float and the level of the water.

9. Another expedient is sometimes used, which consists of a tube let in through the top of the boiler, and descending to a point below which the water ought not to fall: at the top of this tube is fixed a *steam whistle*.

10. So long as the level of the water is above the lower end of the tube, a column

of water will be sustained in the tube by the pressure of the steam within the boiler; but when the level subsides below the mouth of the tube, then steam, rushing through the tube, will issue from the whistle, and produce an alarm which will give notice of the want of water in the boiler.

11. This last contrivance can only be used in low-pressure boilers, where the column of water which will balance the steam is not too high.

12. It is most necessary at all times that the pressure of the steam within the boiler should be known, and provision should be made to prevent its exceeding a certain limit. This is accomplished by the common *safety valve.*

This valve is an ordinary conical valve, placed in the top of the boiler, and fitting into its seat so as to be steam-tight. It is loaded with a weight which determines the maximum pressure to which the steam is allowed to attain. Thus, if it be intended, as in low-pressure boilers generally, that the steam should not exceed 6 lbs. per square inch, then the safety valve is loaded with a weight, regulated in such proportion to the magnitude of its surface exposed to the steam, that whenever the pressure of the steam exceeds this limit, it forces the valve open, and escapes, until the pressure is reduced to the proper limit.

13. The safety valve, however, affords an indication that the pressure of the steam does not exceed a certain amount, rather than an indication of what that pressure actually is.

14. The *steam gauge* exhibits the exact amount of this pressure.

15. The steam gauge most generally used is that called the Bourdon Steam Gauge. It consists of a metallic tube, closed at one end, and communicating at the other end, by means of a stop-cock, with the boiler. The tube is coiled spirally.

Any variation in the internal pressure causes a corresponding change in the form of the spiral, and these changes are made visible to the eye by means of a needle, actuated by the tube, and traversing a properly divided dial-plate.

16. Owing to the obstruction which the steam encounters in passing through the steam pipes and valves, its pressure undergoes a greater or less diminution on its way to the cylinder. To ascertain the effective pressure, therefore, in the cylinder, a steam gauge is sometimes placed upon the steam pipe, as close as possible to the cylinder.

17. A custom has been adopted too generally of estimating the pressure of the steam in the cylinder by its pressure in the boiler, assuming that between the two there is but a slight difference. Nothing can be more erroneous than this. Between the pressure of the steam in the boiler and in the cylinder there may be almost any amount of difference. If the throttle valve be nearly closed while the pressure of the steam in the boiler is very high, the pressure of steam which works the piston may be very low; and, on the other hand, if the throttle valve be nearly open, there may not be a considerable difference between the two.

18. To calculate, therefore, in general, the effective power of the engine by taking, as is commonly done, the pressure of the steam in the boiler, and multiplying that by the area of the piston and its velocity, is a most fallacious method. The indicator already described may be used to determine the average pressure of steam on the piston, and thus the effective action of the piston may be calculated; or if the actual quantity of water transmitted in the state of steam to the cylinder be known, the mechanical effect of this can be calculated independently of any consideration of the pressure of the steam, or even of the magnitude of the piston. It will, however, be necessary even in this case to determine the resistance of the uncondensed steam.

19. In locomotive engines the pressure of the steam is indicated by a spring steelyard, which is made to act upon the safety valve. (See Section XXVII., title "*Spring*

Safety Valve.") This instrument is in principle precisely the same as the common spring steelyards used in domestic economy. A scale is attached to it, upon which an index plays, by which the pressure on the valve is expressed in lbs. per square inch. The instrument is usually screwed down, so that the valve will only be opened when the steelyard indicates a certain pressure.

20. It is customary, more especially in high-pressure engines, to provide two safety valves, one of which shall be removed from the interference of the engine-man. This precaution prevents the danger which would arise from the engine-man overloading the valve, or from the valve becoming fixed in its seat from accidental causes, which sometimes happens.

21. When a boiler ceases to be worked, and the fire has been extinguished, the steam which filled its interior will be speedily condensed, and the interior would become a vacuum. In this case a prodigious amount of atmospheric pressure, acting on the external surface of the boiler inwards, would have a tendency to crush it. This contingency is sometimes provided against by a safety valve which opens inwards. So long as the boiler is in operation, this valve is kept closed by the pressure of the steam; when it ceases to be worked, it is opened by the pressure of the atmosphere.

22. It is most necessary for the efficient operation of the engine that the state of the vacuum in the condenser should be at all times known. For this purpose an indicator is adopted, called the *barometer gauge*, forming one of the most important appendages of the condensing steam engine. (See Section XXVII., title "*Barometer Gauge.*")

This instrument, as its name imports, is a common barometer; but the top of the tube, instead of being closed, is made to communicate with the condenser. The atmospheric pressure, acting, as usual in barometers, on the mercury in the cistern, presses a column of mercury up the tube. If the vacuum in the condenser were as perfect as that which is at the top of the barometric tube, then the column of mercury in this instrument would stand at exactly the same height as in the common barometer; but as this is never the case, there is a difference of height which is due to the pressure of uncondensed steam and air, which, notwithstanding the action of the air-pump, will always remain in more or less quantity in the condenser. The difference, therefore, between the height of the column of mercury in the barometer gauge communicating with the condenser, and in a true barometer placed near it, will give, in inches of mercury, the pressure which re-acts upon the piston against the steam.

23. In well-managed engines the barometer gauge is seldom more than two inches below the true barometer, which would give a pound per square inch for the pressure re-acting on the piston.

24. If the barometer gauge stand too low, it indicates the presence either of uncondensed vapour or of air in the condenser. This may arise either from too little or too much water being thrown in by the condensing jet. If too little be thrown in, the condensation will be imperfect, and uncondensed vapour will lower the gauge: if too much be thrown in, an accumulation of air will be produced faster than the pump can remove it, and the gauge will be similarly affected. The adjustment of the jet is a matter, therefore, that should be carefully attended to. The cock which governs the jet has a handle to which an index is attached, playing upon a divided scale; and according to the position of that index, the cock is more or less opened or closed.

SECTION XXII.—HOW THE WANTS OF THE BOILER AND ENGINE ARE SUPPLIED AND HOW THEIR OPERATION IS REGULATED.

1. If the work executed by a steam engine were subject to no variation whatever, the rate at which the steam should be supplied to the cylinder and generated in the boiler would be uniform also; and as the production of such steam necessarily bears an uniform ratio to the development of heat in the furnace, this last would be also uniform. The development of heat in the furnace being in direct ratio to the supply of air, or, what is the same, the draught in the chimney, it would follow that an engine perfectly uniform in its action would require an invariable adjustment of the flues, an invariable rate of evaporation in the boiler, and an invariable magnitude of communication between the boiler and cylinder for the supply of steam.

2. But in practice it is found that the work to be executed by machinery of this kind is subject to more or less variation, requiring a greater or less intensity from time to time in the moving power.

3. This necessitates a corresponding variation in the action of the steam in the cylinder. This variation is produced by the *throttle valve*, placed in the pipe by which steam is conducted to the cylinder. (See *fig. art.* 17.) This valve is a circular plate, corresponding nearly with the magnitude of the pipe in which it is placed. It is so constructed as to turn on an axis which coincides with one of its diameters, and its movement is governed by a lever or handle on the outside of the steam pipe. When this circular plate is turned so as to present its edge to the current of steam, that current is allowed to pass without obstruction to the cylinder; but when it is turned so that its face is presented to the steam, the current is altogether stopped. Between these two extreme positions it may have any intermediate inclination by which the flow of steam to the cylinder shall be regulated in any desired manner.

4. Supposing this valve to be adjusted, from time to time, so as to proportion the quantity of steam admitted to the cylinder to the quantity of work to be done, the production of the steam in the boiler will have to be considered. If this production be uniform, it must be adequate in quantity to the greatest amount of steam at any time required by the cylinder.

5. When less than this is admitted to the cylinder by the action of the throttle valve, an accumulation would necessarily take place in the boiler, and the pressure on the safety valve becoming excessive, the surplus steam would blow off. This would occasion, of course, a corresponding waste of fuel. The remedy for this would be a contrivance by which the rate of evaporation in the boiler can be augmented or diminished at pleasure, according to the wants of the cylinder. This will obviously be accomplished by any contrivance which will stimulate or slacken the furnace at pleasure. Now since the action of the furnace is regulated by the intensity of the draught, exactly as the action of the piston is regulated by the intensity of the steam admitted to it, the same kind of regulator may be applied to the one as has been applied to the other. A plate called a *damper* is therefore introduced at some convevient point in the flue near the chimney. This plate is generally made like a sliding shutter. When it is let down, it stops the flue altogether, and the fire would be extinguished; when it is drawn up to the limit of its play, the flue is altogether open, and the draught is at its extreme power: between these limits the damper may have an indefinite variety of positions, leaving more or less of the flue open, so as to give the draught any required intensity.

6. It is easy to imagine an attendant working these two instruments so as to regulate the action of the machinery. When the resistance on the working point is lightened, the throttle valve is partially closed, so as to diminish the supply of steam,

and at the same time the damper is partially closed, so as to diminish the draught: on the other hand, when the load on the machinery is increased, the throttle valve is opened, so as to augment the supply of steam and increase the action on the piston; and the damper is raised, so as to increase the intensity of the combustion and augment the rate of evaporation in the boiler.

7. It would be obviously desirable that these contrivances, which we have here supposed to be regulated at the discretion of the attendant on the engine, should be regulated by the wants of the engine itself, so as to be made *self-acting*, like the valves which regulate the supply of steam to the cylinder.

8. This is accordingly accomplished by very simple and effectual means in low-pressure boilers, to which we more particularly advert at present. A tube is inserted, which descends in the boiler below the level of the water; the pressure of the steam supports in this tube a column of water of a certain height, and as the pressure of the steam varies, this column varies in height. A float is introduced in the tube, and supported by this column of water: a chain attached to this float is conducted over one or more pulleys, and carried to the damper, which is suspended to it. Now, let us suppose the throttle valve either opened or closed, as the case may be. If it be opened, the supply of steam passing from the boiler to the cylinder is augmented; the pressure of steam in the boiler is for the moment diminished by this exhaustion; the column of water in the tube falls by reason of the diminished pressure; the float supported by it falls with it, and, drawing down the chain, draws up the damper; the draft through the furnace is augmented, the combustion is stimulated, the heat which acts on the boiler increased, and the evaporation accelerated until the production of steam becomes adequate to the demands of the cylinder.

9. In this way the varying demands of the cylinder on the boiler are made to vary in a proportional manner the action of the furnace, on which the generation of steam depends: when the cylinder consumes much steam, the damper is kept open; when little, it is partially closed.

10. The superintendence of the damper by the engine-man is therefore superseded. The engine itself works it more regularly and perfectly than could be done by any manual superintendence.

11. This arrangement is called the *self-acting damper*.

12. In steam engines in general, and especially in those used in the manufactories, the rate at which steam is supplied to the cylinder ought to be proportionate to the work which the engine has to perform; if not, whenever the resistance on the engine should be diminished, the speed of the piston would be augmented; and whenever the resistance should be augmented, the speed of the piston would be diminished, and a continually varying and irregular motion would necessarily take place in the engine, and would be transmitted to the machinery which it works. This is in general incompatible with the exigences of the arts and manufactures, in which there is a certain rate of motion or speed which ought to be imparted to the machinery, and which ought neither to be permitted to decline or augment.

13. Now, since occasional variations in the resistance are inevitable, the only way to maintain an uniform velocity in the engine and in the machinery it drives is to provide means of regulating the supply of steam, so that the rate at which it shall flow into the cylinder shall be varied in the exact proportion of the resistance. This might, as I have already stated, be accomplished by the manual superintendence of the throttle valve; but a much more certain and efficacious expedient was supplied in the *governor*, by the fertile invention of Watt.

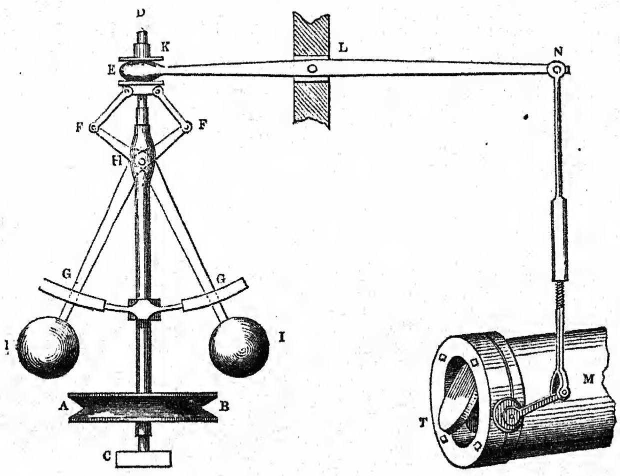
14. To make the principle of the governor comprehended, we must refer to a well-known property of the common pendulum used as the regulator of time-pieces. It is

the property of this instrument, that when it oscillates in obedience to gravity from side to side in a circular arc, the time of its vibration will be the same, whether the arcs in which it vibrates are long or short, provided only the angle of its vibration be not considerable: if the arcs be short, its motion will be slow; if long, its velocity will be proportionally great; and thus, whether long or short, the time of accomplishing a complete vibration will be the same. This well-known property of the pendulum is called *isochronism.*

15. Now if the pendulous knob, instead of vibrating in a circular arc, be made to whirl with a circular motion round an axis, the knob, in virtue of the centrifugal force produced by the rotation, will have a tendency to recede from the axis round which the motion takes place; and when it assumes such a position that the tendency to recede is equal to its tendency to descend, in virtue of its weight, it will remain at a fixed distance from the axis round which it revolves, neither receding from nor approaching to it.

16. It is a property of this arrangement, quite analogous to the isochronism of the pendulum, and, indeed, depending on the same physical principles, that the time of revolution necessary to produce this equilibrium, and to keep the knob at a fixed distance from the axis, without receding from or approaching to it, is the same, whatever be the distance of the knob from the axis, provided only that the angle of obliquity of the rod be not considerable; and even though such angle have some considerable magnitude, the times of revolution corresponding to the state of equilibrium will not be considerably different.

17. This expedient, known by the name of the *conical pendulum,* was applied by Watt, with his usual felicity and success, to the regulation of the throttle valve. The arrangement, as usually adopted, is represented in the following figure. Two balls I are attached to the ends of equal rods of metal, H G. The arrangement is composed



of a series of jointed rods H F E, which play upon a vertical spindle C D, being fixed at H, but capable of sliding upon it at E. When the balls are separated so that the rods H G become more divergent, the arms H F open, and the pivots F, separating, draw down the collar E, which, as I have stated, slides upon the spindle: and on the contrary, when the balls approach each other, the arms H F also approach each other, and the collar E is forced up. Thus, according to the distances of the balls from the

vertical spindle, the collar E ascends or descends. In the collar E is inserted the forked end K of the lever N L K. The end N of this lever is connected, as represented in the figure, with the throttle valve T, and the proportion and position of the rods are so adjusted that when the balls descend towards their lowest position, the throttle valve becomes open; and when they separate, it becomes gradually closed.

A grooved wheel A B, or oftener a toothed pinion, is fixed upon the axle of the spindle, which receives its motion from any convenient part of the machinery.

Now let us suppose that the load on the engine is suddenly diminished. A momentary augmentation of speed will take place in the piston, and an increased velocity be imparted to the wheel A B and the balls of the governor; these balls will consequently fly further from the vertical spindle, the fork K will be drawn down, the throttle valve T partially closed, and the supply of steam to the cylinder diminished.

If, on the other hand, the load on the engine be increased, the speed of the piston will be momentarily slackened, the velocity of the wheel A B will be diminished, the balls will descend and approach the vertical spindle, the fork K will be raised, and the throttle valve T partially opened. In this manner the governor has the effect of admitting at all times to the cylinder just that portion of steam which is necessary to give to the piston the proper velocity, the quantity being always proportioned to the load on the engine.

It is to be understood that this beautiful little instrument exercises powers circumscribed within narrow limits, but these limits are sufficiently extended to accommodate themselves to the variations incidental to the work which the engine performs. If the average amount of work varies from time to time, the governor can be adjusted accordingly.

18. I have already explained in how great a degree the regular supply of water to the boiler is necessary to the efficiency of the machine. Since the water in the boiler will be in the direct proportion of the work executed by the engine and the combustion in the furnace, it seems natural to seek for some self-regulating mode of feeding the boiler, analogous to that which we have described as governing the combustion in the furnace and the supply of steam to the cylinder. It has been already explained that a float within the boiler causes a rod, bearing an index to ascend and descend, indicating always the quantity of water in the boiler.

Now if this rod can be made to act upon a reservoir of water communicating with the interior of the boiler, so as to open the valve and admit water when it descends, and close the valve so as to stop the supply when it ascends, the desired object will be attained. Such an arrangement has accordingly been adopted with complete success in low-pressure boilers, and forms what is called the *self-acting feeder.* To the rod of the float is attached a cord or chain by which it is connected with the end of a lever, which opens and closes a valve placed in the bottom of a small cistern which stands at a sufficient height above the boiler. A tube is inserted in the bottom of this cistern under the valve, which tube descends into the boiler, and in it a column of water is sustained by the pressure of the steam, as already described.

When the level of the water subsides and the boiler requires feeding, the float falls, draws down the rod, opens the valve in the small cistern above, and lets water flow in through the tube: this continues until the level of the water is restored to its proper height, when the valve is closed.

19. But to speak more precisely, this valve is not alternately opened and closed. The float and valve will be so adjusted that the latter is kept just so much open as to allow a stream of water to descend in the tube which is exactly equal to the rate

of evaporation in the boiler, so that the level of the water is kept constantly at the same point.

20. This arrangement, however, is only applicable to low-pressure boilers, for in high-pressure boilers the column of water which would be sustained in the tube would be too high.

21. It is customary to supply the feed cistern just mentioned with the water pumped from the condenser by the air-pump : this water, having a temperature more elevated than that of the atmosphere, carries back to the boiler a portion of heat which would otherwise be wasted.

22. In high-pressure boilers, where this feeding apparatus would be inapplicable, the necessary quantity of water is driven into the boiler by forcing pumps, called *feed-pumps*, which are worked by the engine. The dimensions of these pumps are regulated according to the average evaporating power of the boiler, so that the quantity of water which they throw in shall be exactly equal to the quantity which passes in the state of steam to the cylinder.

23. As this proportion, however, cannot be always precisely maintained, it is necessary to provide means for cutting off the feed-pumps, or throwing them into operation at pleasure. Arrangements of this kind are accordingly provided, and placed at the disposal of the engineer.

24. An easy and obvious expedient suggests itself for cutting off the feed, and supplying it according to the wants of the boiler, which, however, I do not recollect seeing adopted in practice.

25. The float which rises and falls with the level of the water in the boiler might be made to act by its rod upon the gearing of the feed-pumps, exactly as it acts upon the valve in the feed-cistern in low-pressure boilers; so that whenever the level of the water should become too high, the pump should be thrown out of gear; and whenever it was too low, it should be thrown into action.

SECTION XXIII.—HOW THE STEAM ENGINE IS ADAPTED TO THE WORKING OF PUMPS.

1. Hitherto we have considered the piston as driven in both directions, upwards and downwards, by steam, a vacuum being produced alternately on the side towards which it moves.

2. When the engine is applied to work a common lifting-pump, the force being only required to be exerted when the pump buckets are raised, but not in their descent, an arrangement would be required in the cylinder by which the piston should be only driven by steam in its descent, the pump buckets being then raised at the other end of the beam; but in its ascent the piston would be drawn up by the weight of the descending buckets and rods, without any aid from the steam. Engines adapted to work such pumps are therefore so arranged that the valve shall only admit steam above the piston, a vacuum being made below it in the descent. Engines constructed in this manner are called *single-acting engines*, while those in which the steam acts both above and below the piston are called *double-acting engines*.

3. The single-acting engine in its principle differs in no respect from those we have described. A valve is provided at the top of the cylinder, by which steam is admitted above the piston when it begins to descend; another valve is provided at the bottom, by which the steam under the piston passes to the condenser; and the piston descends exactly in the same manner as in the double-acting engine. But when the piston has reached the bottom of the cylinder, a valve is opened which gives a communication between the top and the bottom of the cylinder, so that the steam which has just pressed the piston down now passes equally above and

below it. The piston being then drawn up by the weight of the descending buckets, the steam which was above it passes below it, through a tube attached, in which the valve just mentioned, communicating between the top and bottom of the cylinder, is placed. When the piston has reached the top of the cylinder, the steam which previously filled the cylinder above the piston will now fill it below the piston; and when the piston is about to descend by the pressure of fresh steam admitted above it, the steam below it is discharged to the condenser by another valve, already mentioned, and so the operation proceeds.

4. These single-acting engines are only applicable to pumping or to some other operation in which an intermitting force, acting in one direction only, is required.

5. The double-acting engine may, however, be also applied to pumping by the use of a double-acting pump, a variety of forms of which are familiar to engineers.

6. The most remarkable examples of the application of the steam-engine to pumping are presented in the mining districts of Cornwall, where engines constructed on an enormous scale are applied to the drainage of the mines. The largest steam engines in the world are used for this purpose. Cylinders 8 and 9 feet in diameter are not unprecedented. The expansive principle may here be applied without limit, inasmuch as regularity of motion is not necessary. Steam having a pressure of 50 lbs. per square inch above the atmosphere is admitted to act on the piston, and cut off after performing from $\frac{1}{8}$ to $\frac{1}{12}$ of the stroke, the remainder of the stroke being effected by the expansion alone of the steam.

SECTION XXIV.—HOW THE STEAM ENGINE IS CONSTRUCTED IN CASES WHERE A CONDENSING APPARATUS IS INADMISSIBLE.

1. It will be perceived that the advantages obtained by the vacuum produced by the condensation of steam are not without drawbacks. The machinery for condensation is costly, bulky, and heavy, and moreover consumes a considerable portion of the moving power in working it. The condenser requires a cistern of cold water, in which it is submerged. The cistern must be kept constantly supplied with cold water, for which purpose a pump called the *cold water pump*, must be worked by the engine. The water and air admitted by the condensing jet must be continually pumped out by the air-pump. In many cases the steam engine is worked in situations in which a sufficient supply of cold water cannot be procured, and where the weight and bulk of the condenser, air-pump, and cold water pump, would be inadmissible. In these cases the power of the steam must be worked without the advantage of the vacuum on the other side of the piston. Engines thus constructed are called *non-condensing engines*, and sometimes, though not with strict propriety, *high-pressure engines*. Steam having a greater pressure than that of the atmosphere being admitted on one side of the piston, and the other side being left in open communication with the atmosphere, the piston will be urged forwards by a force proportional to the excess of the steam pressure above the pressure of the atmosphere, the friction, and other resistances. When the piston is thus drawn to the other end of the cylinder, the steam being admitted on the opposite side of the piston, and the contrary side being open to the atmosphere, the piston will in like manner be urged back again.

2. Between the *mechanism* by which the admission and emission of the steam is effected in this machinery, and that which we have described in the condensing engine, there is no real difference. Whether the steam be allowed to escape to the condenser or into the open atmosphere, the mechanism which governs its admission and escape will be the same.

3. As the pressure of the steam in such machines must necessarily exceed that of the atmosphere, in a sufficient proportion to supply a force necessary for the purpose

to which the machine is applied, the pressure is always much greater than is necessary where condensation is used; and hence the application of the term *high pressure engines* to such machines; but the use of the term is objectionable, inasmuch as steam of an equally high pressure is often used in engines in which the steam is condensed and a vacuum produced. An example of this is presented in the engines used in Cornwall, where steam having a pressure of 50 lbs. or upwards on the square inch is used.

4. Properly speaking, therefore, *high pressure engines* consist of two classes; those in which the steam is not condensed, and those in which it is condensed.

5. The most proper classification of engines, therefore, is into *condensing* and *non-condensing engines;* the latter being always high-pressure engines, and the former sometimes high-pressure and sometimes low-pressure.

6. By low-pressure engines is to be understood those in which the safety valve on the boiler is loaded at the rate of 4 to 6 lbs. per square inch.

7. High-pressure engines is a term rather indefinite; but where the valve is loaded with 20 lbs. or upwards per square inch, the machine is generally so called.

8. In the United States, the use of high-pressure steam is much more universal than in England, and 20 lbs. upon a square inch of the safety-valve would hardly be denominated high pressure. This will be understood when it is stated that from 120 to 150 lbs. per square inch is not a very uncommon pressure to use.

9. In locomotive engines, the condensing apparatus is excluded for obvious reasons. The pressure in these is usually from 100 to 150 lbs. per square inch. The steam which escapes from the cylinder after working the engine, is ejected up the chimney, where it plays the part of a blower, and supplies that want of elevation of the chimney which circumstances here exclude.

SECTION XXV.—HOW THE MECHANICAL PRESSURE OF THE STEAM ON THE PISTON IS LIMITED, AND HOW THE SPEED OF THE PISTON IS AFFECTED BY THIS.

It is commonly but erroneously supposed that the pressure which the steam exerts on the piston of an engine can be augmented or diminished at pleasure by augmenting or diminishing the pressure of the steam in the boiler. A moment's attention to some universal principles of mechanical science will be sufficient to rectify this error.

It is an established principle, that when a body which offers a definite resistance to motion is impelled by a force whose pressure is precisely equal to that resistance, the body so acted upon must be in one of two states, viz. either at rest, or moving with an uniform velocity.

This principle is convertible. A state of rest or of uniform motion presumes that the body in such state must be acted upon by forces *in equilibrio*,—that is to say, if it be in motion, the energy of the forces which impel it must be precisely equivalent to the resistance which it offers to them.

To illustrate this by a practical example, let us suppose that a carriage placed on an uniform and level road is drawn by a horse at a perfectly uniform speed. The resistance in this case which the carriage offers to the draught is precisely equivalent to the force impressed by the horse on the collar.

If an experimental proof of this be required, it may be easily given. Let a carriage be placed on any level surface, and drawn by a weight carried over a pulley. When its motion is uniform, it will be found that the amount of the weight which gives it such motion is precisely equal to the resistance of the carriage.

But it will be asked, how can the energy of the impelling forces be greater or less than the resistance, if the object to which it is applied be in motion? If it be greater than the resistance, it cannot do more than move it; if it be less than the resistance, why does not the object stop altogether? Admitting that a moving force greater in

amount than the resistance of the body moved can be applied, it may be further asked, what becomes of the surplus of such moving force? It is clear that the resistance cannot absorb more than its own amount of the moving force: on what, then, is the surplus expended?

Let the simple and familiar example of a carriage moved on a level road be taken. Let us suppose that the force exercised on the carriage is 150 lbs. while the resistance of the carriage to the moving power is only 100 lbs. On what object, then, are the other 50 lbs. expended?

The answer to this is extremely simple, and easily understood. When the moving force is thus greater in intensity than the resistance, the motion imparted to the body to which it is applied is not, as above, an uniform speed, but a speed constantly accelerated: in every succeeding second of time the moving force imparts to the body an increased velocity, and consequently an increased momentum. It is by this augmentation of momentum, then, that the surplus moving force is absorbed. It is, therefore a living force. It is not, properly speaking, extinguished, as in that portion of the moving force which is *in equilibrio* with the resistance. The momentum which it produces in the moving body will be retained and expended upon something before the moving body can come to a state of rest.

Accelerated motion is, then, the consequence of the moving force exceeding in amount the resistance of the body moved.

Analogy will at once raise the presumption, that a gradually retarded motion will be the consequence of the moving force being less in intensity than the resistance of the body moved.

The moving force in this case balances, or as it were extinguishes so much of the resistance as is equal to its intensity; the excess of the resistance, however, remains to be accounted for. What is its effect, and what becomes of it? We suppose the body to be already in motion; its weight or mass has therefore a certain momentum, which, by the common properties of matter, gives it a tendency to continue in motion. This tendency is opposed by that portion of the resistance which is not balanced by the moving force. This portion of the resistance, then gradually robs the moving body of its momentum, makes it move more and more slowly, and at length, extinguishing all the momentum, brings the body to a state of rest.

Thus it will be clearly understood that any inequality between the intensity of the pressure, or traction, or impulsion, by whichever term the moving force be designated, and the intensity of the resistance, will be attended with an accelerated or retarded motion in the body moved, according as the excess lies on the side of the moving power or on the side of the resistance.

There is nothing new in these principles. They are, in fact, the established principles of general mechanics, perfectly familiar to all who have cultivated the higher departments of science.

Let us apply these principles to the case of a steam engine.

The piston is in this case the body moved. The boiler is the source of the moving power. To simplify the case, we shall imagine the motion of the piston to take place constantly in one direction, instead of being reciprocated from end to end of the cylinder.

Now it follows from what has just been explained, that if the motion of the piston in the cylinder be uniform, the pressure of the steam which impels it cannot by any mechanical possibility be different from the amount of the resistance which the piston offers. You may load the safety valve as you please: you may vary the condition of the boiler in any imaginable manner, and the pressure of the steam in that vessel may have any intensity whatever; but it is demonstrably certain that the pressure of

the steam in the cylinder cannot be either greater or less than such as would be necessary on the entire surface of the piston to produce an action equal to its resistance. This is as certain as the conclusion of any problem in common geometry.

But then, it may be objected, we can have no power to vary the pressure of the steam in the boiler, inasmuch as the resistance of the piston has no connection with the source of the moving power.

I have explained in a former section that the pressure of steam in the boiler, though it can never be *less* than the pressure of steam in the cylinder, may be to any desired extent greater: the action of the throttle valve explains this: the more the throttle valve is contracted, and the smaller the orifice through which the steam has to pass into the cylinder, the greater will be the ratio of its pressure in the boiler to its pressure in the cylinder. There is, then, a minor limit to the pressure of steam in the boiler; it cannot be less than such a pressure as would produce on the piston an action equal to its resistance.

What is, on the other hand, the major limit of the pressure of steam in the boiler? This limit is obviously determined by the load on the safety valve: when the steam exceeds this limit, the safety valve will be opened, and the surplus pressure reduced by escape.

It thus appears that the piston and the safety valve supply the two limits of the possible pressure of steam in the boiler. The pressure per square inch of the steam in the boiler cannot be less than the resistance per square inch of the piston, nor greater than the pressure per square inch on the safety valve.

In the ordinary action of an engine, the motion must in the main be uniform. Acceleration or retardation are conditions exceptional and occasional. When the piston is first put in motion from a state of rest, its motion is accelerated until it has attained its normal and regular speed; when the engine is about to be stopped, its motion is gradually retarded until the resistance extinguishes the momentum of the machinery.

When the piston and other reciprocating parts of the machinery change the direction of their motion at each extremity of the stroke, they will be for a short interval, before and after the moment the direction changes, retarded and accelerated; and this retardation and acceleration would be very perceptible, were it not for the fly-wheel: but the momentum of the fly-wheel, as well in consequence of its weight as of the velocity of the matter forming its rim, so prodigiously exceeds the momentum of the reciprocating parts of the machinery, that the effect of acceleration and retardation in the latter is altogether effaced by the great momentum of the revolving mass of the former.

It is for this reason that the fly-wheel justifies us practically in our reasoning in assuming the piston as moving uniformly and constantly in one direction, instead of reciprocating.

When the steam is used expansively, being cut off at one-half, or any other fraction of the stroke, the impelling power necessarily varies in intensity; and as the resistance does not vary in intensity, or at least does not vary in the same manner and proportion, there will consequently not be an equilibrium between the moving power and the resistance, and the motion therefore cannot be uniform.

When steam is thus applied, the pressure, when first admitted on the piston, is greater than the resistance; and so long as the steam valve is open, the motion of the piston will be accelerated. When it is closed, and the steam begins to expand, it gradually diminishes in intensity. The accelerated motion of the piston will, however, continue until the pressure of the steam becomes equal to the resistance. Further expansion rendering it less powerful than the resistance, the motion of the piston will be retarded to the end of the stroke.

This series of effects is repeated at each stroke of the piston.

Now although in this case the motion of the piston during any one stroke is variable, yet the average motion of the machine will be uniform: although throughout a single stroke the piston be alternately accelerated and retarded, yet the number of strokes performed by the machine per minute will be the same. The average velocity will be uniform, although the velocity within the limit of a single stroke be not so.

But even this variation within the limits of each stroke is almost effaced by the action of the fly-wheel, which absorbs the acceleration and repairs the retardation by giving and taking momentum, as already described.

I have spoken of the uniform velocity of the piston, which, whether it be maintained in the literal sense of the term, or only on the average, as estimated by the number of strokes per minute, must in every case be the result of an equilibrium between the average moving force of the steam and the resistance of the machinery. But what, it may be asked, determines the rate of this uniform speed? What conditions are they which can determine whether the piston shall move 200 feet or 500 feet per minute?

This is obviously determined by the rate at which the boiler is capable of supplying steam of the requisite pressure to the cylinder. Let the resistance on the piston be estimated; say that it is 20 lbs. per square inch of its surface; then the boiler must be capable of supplying steam of 20 lbs. pressure per square inch, in such measure as to enable the piston to move at the required speed.

Let us assume, for example, that the required speed is 2000 feet per minute, or 12,000 feet per hour, and that the area of the piston is 5 square feet; then, to enable the piston to advance through 12,000 feet, a column of steam must follow it, 12,000 feet in length and 5 square feet in its section, which gives 60,000 cubic feet of steam. But steam having the pressure of 20 lbs. per square inch bears to the bulk of water which produces it the proportion of 1281 to 1; therefore, if we divide 60,000 by 1281, we shall find the number of cubic feet of water which must be supplied in the state of steam by the boiler to the cylinder in an hour.

This division gives 47, very nearly. This boiler therefore, must in this case evaporate 47 cubic feet of water per hour, or, according to the conventional standard of boiler-makers, be a boiler of 47 horse-power.

In general this calculation may be made by the aid of the following Tables.

TABLE I.—AREAS OF PISTONS.

Dia.	Area.	Dia.	Area.	Dia.	Area.	Dia.	Area.	Dia.	Area.
Inch.	Inches.	I ch.	Inches.	Inch.	Inches.	Inch.	Inches.	Inch.	Inches
1	·785	3	7·068	5	19·635	7	38·484	9	63·617
1/8	·994	1/8	7·669	1/8	20·629	1/8	39·871	1/8	65·396
1/4	1·227	1/4	8·295	1/4	21·647	1/4	41·282	1/4	67·200
3/8	1·484	3/8	8·946	3/8	22·690	3/8	42·718	3/8	69·029
1/2	1·767	1/2	9·621	1/2	23·758	1/2	44·178	1/2	70·882
5/8	2·073	5/8	10·320	5/8	24·850	5/8	45·663	5/8	72·759
3/4	2·405	3/4	11·044	3/4	25·967	3/4	47·173	3/4	74·662
7/8	2·761	7/8	11·793	7/8	27·108	7/8	48·707	7/8	76·588
2	3·141	4	12·566	6	28·274	8	50·265	10	78·540
1/8	3·546	1/8	13·364	1/8	29·464	1/8	51·848	1/8	80·515
1/4	3·976	1/4	14·186	1/4	30·679	1/4	53·456	1/4	82·516
3/8	4·430	3/8	15·033	3/8	31·919	3/8	55·088	3/8	84·540
1/2	4·908	1/2	15·904	1/2	33·183	1/2	56·745	1/2	86·590
5/8	5·411	5/8	16·800	5/8	34·471	5/8	58·426	5/8	88·664
3/4	5·939	3/4	17·720	3/4	35·784	3/4	60·132	3/4	90·762
7/8	6·491	7/8	18·665	7/8	37·122	7/8	61·862	7/8	92·885

TABLE I.—*Continued.*

Dia.	Area.	Dia.	Area.	Dia.	Area.	Dia.	Area.	Dia.	Area.	Dia.	Inches.
Inch.	Inches.	Inch.	Inches.	Inch.	Inches.	Inch.	Inches.	Inch.	Inches.	Inch.	Inches.
11	95·033	19	283·52	27	572·55	35	962·11	43	1452·2	51	2042·8
⅛	97·205	⅛	287·27	⅛	577·87	⅛	968·99	⅛	1460·6	⅛	2052·8
¼	99·402	¼	291·03	¼	583·20	¼	975·90	¼	1469·1	¼	2062·9
⅜	101·62	⅜	294·83	⅜	588·57	⅜	982·84	⅜	1477·6	⅜	2072·9
½	103·86	½	298·64	½	593·95	½	989·80	½	1486·1	½	2083·0
⅝	106·13	⅝	302·48	⅝	599·37	⅝	996·78	⅝	1494·7	⅝	2093·2
¾	108·43	¾	306·35	¾	604·80	¾	1003·7	¾	1503·3	¾	2103·3
⅞	110·75	⅞	310·24	⅞	610·26	⅞	1010·8	⅞	1511·9	⅞	2113·5
12	113·09	20	314·16	28	615·75	36	1017·8	44	1520·5	52	2123·7
⅛	115·46	⅛	318·09	⅛	621·26	⅛	1024·9	⅛	1529·1	⅛	2133·9
¼	117·85	¼	322·06	¼	626·79	¼	1032·0	¼	1537·8	¼	2144·1
⅜	120·27	⅜	326·05	⅜	632·35	⅜	1039·1	⅜	1546·5	⅜	2154·4
½	122·71	½	330·06	½	637·94	½	1046·3	½	1555·2	½	2164·7
⅝	125·18	⅝	334·10	⅝	643·54	⅝	1053·5	⅝	1564·0	⅝	2175·0
¾	127·67	¾	338·16	¾	649·18	¾	1060·7	¾	1572·8	¾	2185·4
⅞	130·19	⅞	342·25	⅞	654·83	⅞	1067·9	⅞	1581·6	⅞	2195·7
13	132·73	21	346·36	29	660·52	37	1075·2	45	1590·4	53	2206·1
⅛	135·29	⅛	350·49	⅛	666·22	⅛	1082·4	⅛	1599·2	⅛	2216·6
¼	137·88	¼	354·65	¼	671·95	¼	1089·7	¼	1608·1	¼	2227·0
⅜	140·50	⅜	358·84	⅜	677·71	⅜	1097·1	⅜	1617·0	⅜	2237·5
½	143·13	½	363·05	½	683·49	½	1104·4	½	1625·9	½	2248·0
⅝	145·80	⅝	367·28	⅝	689·29	⅝	1111·8	⅝	1634·9	⅝	2258·5
¾	148·48	¾	371·54	¾	695·12	¾	1119·2	¾	1643·8	¾	2269·0
⅞	151·20	⅞	375·82	⅞	700·98	⅞	1126·6	⅞	1652·8	⅞	2279·6
14	153·93	22	380·13	30	706·86	38	1134·1	46	1661·9	54	2290·2
⅛	156·69	⅛	384·46	⅛	712·76	⅛	1141·5	⅛	1670·9	⅛	2300·8
¼	159·48	¼	388·82	¼	718·69	¼	1149·0	¼	1680·0	¼	2311·4
⅜	162·29	⅜	393·20	⅜	724·64	⅜	1156·6	⅜	1689·1	⅜	2322·1
½	165·13	½	397·60	½	730·61	½	1164·1	½	1698·2	½	2332·8
⅝	167·98	⅝	402·03	⅝	736·61	⅝	1171·7	⅝	1707·3	⅝	2343·5
¾	170·87	¾	406·49	¾	742·64	¾	1179·3	¾	1716·5	¾	2354·2
⅞	173·78	⅞	410·97	⅞	748·69	⅞	1186·9	⅞	1725·7	⅞	2365·0
15	176·71	23	415·47	31	754·76	39	1194·5	47	1734·9	55	2375·8
⅛	179·67	⅛	420·00	⅛	760·86	⅛	1202·2	⅛	1744·1	⅛	2386·6
¼	182·65	¼	424·55	¼	766·99	¼	1209·9	¼	1753·4	¼	2397·4
⅜	185·66	⅜	429·13	⅜	773·14	⅜	1217·6	⅜	1762·7	⅜	2408·3
½	188·69	½	433·73	½	779·31	½	1225·4	½	1772·0	½	2419·2
⅝	191·74	⅝	438·36	⅝	785·51	⅝	1233·1	⅝	1781·3	⅝	2430·1
¾	194·82	¾	443·01	¾	791·73	¾	1240·9	¾	1790·7	¾	2441·0
⅞	197·93	⅞	447·69	⅞	797·97	⅞	1248·7	⅞	1800·1	⅞	2452·0
16	201·06	24	452·39	32	804·24	40	1256·5	48	1809·5	56	2463·0
⅛	204·21	⅛	457·11	⅛	810·54	⅛	1264·5	⅛	1818·9	⅛	2474·0
¼	207·39	¼	461·86	¼	816·86	¼	1272·3	¼	1828·4	¼	2485·0
⅜	210·59	⅜	466·63	⅜	823·21	⅜	1280·3	⅜	1837·9	⅜	2496·1
½	213·82	½	471·43	½	829·57	½	1288·2	½	1847·4	½	2507·1
⅝	217·07	⅝	476·25	⅝	835·97	⅝	1296·2	⅝	1856·9	⅝	2518·2
¾	220·35	¾	481·10	¾	842·39	¾	1304·2	¾	1866·5	¾	2529·4
⅞	223·65	⅞	485·97	⅞	848·83	⅞	1312·2	⅞	1876·1	⅞	2540·5
17	226·98	25	490·87	33	855·30	41	1320·2	49	1885·7	57	2551·7
⅛	230·33	⅛	495·79	⅛	861·79	⅛	1328·3	⅛	1895·3	⅛	2562·9
¼	233·70	¼	500·74	¼	868·30	¼	1336·4	¼	1905·0	¼	2574·1
⅜	237·10	⅜	505·71	⅜	874·84	⅜	1344·5	⅜	1914·7	⅜	2585·4
½	240·52	½	510·70	½	881·41	½	1352·6	½	1924·4	½	2596·7
⅝	243·97	⅝	515·72	⅝	888·00	⅝	1360·8	⅝	1934·1	⅝	2608·0
¾	247·45	¾	520·76	¾	894·61	¾	1369·0	¾	1943·9	¾	2619·3
⅞	250·94	⅞	525·83	⅞	901·25	⅞	1377·2	⅞	1953·6	⅞	2630·7
18	254·46	26	530·93	34	907·92	42	1385·4	50	1963·5	58	2642·0
⅛	258·01	⅛	536·04	⅛	914·61	⅛	1393·7	⅛	1973·3	⅛	2653·4
¼	261·58	¼	541·18	¼	921·32	¼	1401·9	¼	1983·1	¼	2664·9
⅜	265·18	⅜	546·35	⅜	928·06	⅜	1410·2	⅜	1993·0	⅜	2676·3
½	268·80	½	551·54	½	934·82	½	1418·6	½	2002·9	½	2687·8
⅝	272·44	⅝	556·76	⅝	941·60	⅝	1426·9	⅝	2012·8	⅝	2699·3
¾	276·11	¾	562·00	¾	948·41	¾	1435·3	¾	2022·8	¾	2710·8
⅞	279·81	⅞	567·26	⅞	955·25	⅞	1443·7	⅞	2032·8	⅞	2722·4

TABLE I.—*Continued.*

Dia.	Area.	Dia.	Area.	Dia.	Area.	Dia.	Area.	Dia.	Area.	Dia.	Area.
Inch	Inches.	Inch.	Inches.	Inch.	Inches.	Inch.	Inches.	Inch.	Inches.	Inch.	Area.
59	2733·9	66	3421·2	73	4185·3	80	5026·5	87	5944·6	94	6939·7
⅛	2745·5	⅛	3434·1	⅛	4199·7	⅛	5042·2	⅛	5961·7	⅛	6958·2
¼	2757·1	¼	3447·1	¼	4214·1	¼	5058·0	¼	5978·9	¼	6976·7
⅜	2768·8	⅜	3460·1	⅜	4228·5	⅜	5073·7	⅜	5996·0	⅜	6995·2
½	2780·5	½	3473·2	½	4242·9	½	5089·5	½	6013·2	½	7013·8
⅝	2792·2	⅝	3486·3	⅝	4257·3	⅝	5105·4	⅝	6030·4	⅝	7032·3
¾	2803·9	¾	3499·3	¾	4271·8	¾	5121·2	¾	6047·6	¾	7050·9
⅞	2815·6	⅞	3512·5	⅞	4286·3	⅞	5137·1	⅞	6064·8	⅞	7069·5
60	2827·4	67	3525·6	74	4300·8	81	5153·0	88	6082·1	95	7088·2
⅛	2839·2	⅛	3538·8	⅛	4315·3	⅛	5168·9	⅛	6099·4	⅛	7106·9
¼	2851·0	¼	3552·0	¼	4329·9	¼	5184·8	¼	6116·7	¼	7125·5
⅜	2862·8	⅜	3565·2	⅜	4344·5	⅜	5200·8	⅜	6134·0	⅜	7144·3
½	2874·7	½	3578·4	½	4359·1	½	5216·8	½	6151·4	½	7163·0
⅝	2886·6	⅝	3591·7	⅝	4373·8	⅝	5232·8	⅝	6168·8	⅝	7181·8
¾	2898·5	¾	3605·0	¾	4388·4	¾	5248·8	¾	6186·2	¾	7200·5
⅞	2910·5	⅞	3618·3	⅞	4403·1	⅞	5264·9	⅞	6203·6	⅞	7219·4
61	2922·4	68	3631·6	75	4417·8	82	5281·0	89	6221·1	96	7238·2
⅛	2934·4	⅛	3645·0	⅛	4432·6	⅛	5297·1	⅛	6238·6	⅛	7257·1
¼	2946·4	¼	3658·4	¼	4447·3	¼	5313·2	¼	6256·1	¼	7275·9
⅜	2958·5	⅜	3671·8	⅜	4462·1	⅜	5329·4	⅜	6273·6	⅜	7294·9
½	2970·5	½	3685·2	½	4476·9	½	5345·6	½	6291·2	½	7313·8
⅝	2982·6	⅝	3698·7	⅝	4491·8	⅝	5361·8	⅝	6308·8	⅝	7332·8
¾	2994·7	¾	3712·2	¾	4506·6	¾	5378·0	¾	6326·4	¾	7351·7
⅞	3006·9	⅞	3725·7	⅞	4521·5	⅞	5394·3	⅞	6344·0	⅞	7370·7
62	3019·0	69	3739·2	76	4536·4	83	5410·6	90	6361·7	97	7389·8
⅛	3031·2	⅛	3752·8	⅛	4551·4	⅛	5426·9	⅛	6379·4	⅛	7408·8
¼	3043·4	¼	3766·4	¼	4566·3	¼	5443·2	¼	6397·1	¼	7427·9
⅜	3055·7	⅜	3780·0	⅜	4581·3	⅜	5459·6	⅜	6414·8	⅜	7447·0
½	3067·9	½	3793·6	½	4596·3	½	5476·0	½	6432·6	½	7466·2
⅝	3080·2	⅝	3807·3	⅝	4611·3	⅝	5492·4	⅝	6450·4	⅝	7485·3
¾	3092·5	¾	3821·0	¾	4626·4	¾	5508·8	¾	6468·2	¾	7504·5
⅞	3104·8	⅞	3834·7	⅞	4641·5	⅞	5525·3	⅞	6486·0	⅞	7523·7
63	3117·2	70	3848·4	77	4656·6	84	5541·7	91	6503·8	98	7542·9
⅛	3129·6	⅛	3862·2	⅛	4671·7	⅛	5558·2	⅛	6521·7	⅛	7562·2
¼	3142·0	¼	3875·9	¼	4686·9	¼	5574·8	¼	6539·6	¼	7581·5
⅜	3154·4	⅜	3889·8	⅜	4702·1	⅜	5591·3	⅜	6557·6	⅜	7600·8
½	3166·9	½	3903·6	½	4717·3	½	5607·9	½	6575·5	½	7620·1
⅝	3179·4	⅝	3917·4	⅝	4732·5	⅝	5624·5	⅝	6593·5	⅝	7639·4
¾	3191·9	¾	3931·3	¾	4747·7	¾	5641·1	¾	6611·5	¾	7658·8
⅞	3204·4	⅞	3945·2	⅞	4763·0	⅞	5657·8	⅞	6629·5	⅞	7678·2
64	3216·9	71	3959·2	78	4778·3	85	5674·5	92	6647·6	99	7697·7
⅛	3229·5	⅛	3973·1	⅛	4793·7	⅛	5691·2	⅛	6665·7	⅛	7717·1
¼	3242·1	¼	3987·1	¼	4809·0	¼	5707·9	¼	6683·8	¼	7736·6
⅜	3254·8	⅜	4001·1	⅜	4824·4	⅜	5724·6	⅜	6701·9	⅜	7756·1
½	3267·4	½	4015·1	½	4839·8	½	5741·4	½	6720·0	½	7775·6
⅝	3280·1	⅝	4029·2	⅝	4855·2	⅝	5758·2	⅝	6738·2	⅝	7795·2
¾	3292·8	¾	4043·2	¾	4870·7	¾	5775·0	¾	6756·4	¾	7814·7
⅞	3305·5	⅞	4067·3	⅞	4886·1	⅞	5791·9	⅞	6776·4	⅞	7834·3
65	3318·3	72	4071·5	79	4901·6	86	5808·8	93	6792·9	100	7854·0
⅛	3331·0	⅛	4085·6	⅛	4917·2	⅛	5825·7	⅛	6811·1		
¼	3343·8	¼	4099·8	¼	4932·7	¼	5842·6	¼	6829·4		
⅜	3356·7	⅜	4114·0	⅜	4948·3	⅜	5859 5	⅜	6847·8		
½	3369·5	½	4128·2	½	4963·9	½	5876·5	½	6866·1		
⅝	3382·4	⅝	4142·5	⅝	4979·5	⅝	5893·5	⅝	6884·5		
¾	3395·3	¾	4156·7	¾	4995·1	¾	5910·5	¾	6902·9		
⅞	3408·2	⅞	4171·0	⅞	5010·8	⅞	5927·6	⅞	6921·3		

By this Table, when the number of inches in the diameter of the piston is known, the number of square inches in its area can be found on inspection.

Question I.—Given the diameter of the piston in inches, to find its area in square feet.

Rule I.—Find in Table I. the number of square inches in the area. Divide the number thus found by 144. The quotient will be the area of the piston in square feet.

Example.—To find the area of a piston in square feet whose diameter is $86\frac{3}{4}$ inches.

By Table I. we find that the area in square inches is 5910·5. Dividing this by 144 we obtain

$$\begin{array}{r} 144)5910{\cdot}5 \\ \hline 41{\cdot}04 \end{array}$$

which is the area in square feet.

Question II.—Given the diameter of the piston in inches, and its speed in feet per minute, to find the number of cubic feet of steam per hour which pass through the cylinder.

Rule 2.—By Rule 1, find the area of the piston in square feet. Multiply this by the speed of the piston in feet per minute, and the product will be the number of cubic feet of steam which pass through the cylinder per minute. Multiply this last by 60, and the product is the number of cubic feet per hour.

Example.—A 50-inch piston moves at the rate of 180 feet per minute. What number of cubic feet of steam per hour pass through the cylinder?

By Rule 1 we find the area of the piston to be 17·36 square feet.

Multiply this by 180 :

$$\begin{array}{r} 17{\cdot}36 \\ 180 \\ \hline 3124{\cdot}80 \\ 60 \\ \hline 187488{\cdot}00 \end{array}$$

which is the number of cubic feet of steam per hour which pass through the cylinder.

In the following Table is given, in the 1st column, the total pressure of steam in pounds per square inch; in the 2nd column, the corresponding temperature; in the 3rd column, the number of cubic inches of steam which would be produced by one cubic inch of water; and in the 4th column, the total mechanical effect produced by the evaporation of a cubic inch of water under the pressure expressed in the first column.

TABLE II.

Total Pressure in lbs. per sq. inch.	Corresponding Temperature.	Cubic inches of Steam produced by a cubic inch of Water.	Mechanical Effect of a cubic inch of Water evaporated in lbs. raised 1 ft.	Total Pressure in lbs. per sq. inch.	Corresponding Temperature.	Cubic inches of Steam produced by a cubic inch of Water.	Mechanical Effect of a cubic inch of Water evaporated in lbs. raised 1 ft.
1	102·9	20868	1739	14	209·1	1778	2074
2	126·1	10874	1812	15	212·8	1669	2086
3	141·0	7437	1859	16	216·3	1573	2097
4	152·3	5685	1895	17	219·6	1488	2107
5	161·4	4617	1924	18	222·7	1411	2117
6	169·2	3897	1948	19	225·6	1343	2126
7	175·9	3376	1969	20	228·5	1281	2135
8	182·0	2983	1989	21	231·2	1225	2144
9	187·4	2674	2006	22	233·8	1174	2152
10	192·4	2426	2022	23	236·3	1127	2160
11	197·0	2221	2036	24	238·7	1084	2168
12	201·3	2050	2050	25	241·0	1044	2175
13	205·3	1904	2063	26	243·3	1007	2182

TABLE II.—*Continued.*

Total Pressure in lbs. per sq. inch.	Corre-sponding Tempera-ture.	Cubic inches of Steam produced by a cubic inch of Water.	Mechanical Effect of a cubic inch of Water evaporated in lbs. raised 1 ft.	Total Pressure in lbs. per sq. inch.	Corre-sponding Tempera-ture.	Cubic inches of Steam produced by a cubic inch of Water.	Mechanical Effect of a cubic inch of Water evaporated in lbs. raised 1 ft.
27	245·5	973	2189	71	307·4	403	2385
28	247·6	941	2196	72	308·4	398	2388
29	249·6	911	2202	73	309·3	393	2391
30	251·6	883	2209	74	310·3	388	2394
31	253·6	857	2215	75	311·2	383	2397
32	255·5	833	2221	76	312·2	379	2400
33	257·3	810	2226	77	313·1	374	2403
34	259·1	788	2232	78	314·0	370	2405
35	260·9	767	2238	79	314·9	366	2408
36	262·6	748	2243	80	315·8	362	2411
37	264·3	729	2248	81	316·7	358	2414
38	265·9	712	2253	82	317·6	354	2417
39	267·5	695	2259	83	318·4	350	2419
40	269·1	679	2264	84	319·3	346	2422
41	270·6	664	2268	85	320·1	342	2425
42	272·1	649	2273	86	321·0	339	2427
43	273·6	635	2278	87	321·8	335	2430
44	275·0	622	2282	88	322·6	332	2432
45	276·4	610	2287	89	323·5	328	2435
46	277·8	598	2291	90	324·3	325	2438
47	279·2	586	2296	91	325·1	322	2440
48	280·5	575	2300	92	325·9	319	2443
49	281·9	564	2304	93	326·7	316	2445
50	283·2	554	2308	94	327·5	313	2448
51	284·4	544	2312	95	328·2	310	2450
52	285·7	534	2316	96	329·0	307	2453
53	286·9	525	2320	97	329·8	304	2455
54	288·1	516	2324	98	330·5	301	2457
55	289·3	508	2327	99	331·3	298	2460
56	290·5	500	2331	100	332·0	295	2462
57	291·7	492	2335	110	339·2	271	2486
58	292·9	484	2339	120	345·8	251	2507
59	294·2	477	2343	130	352·1	233	2527
60	295·6	470	2347	140	357·9	218	2545
61	296·9	463	2351	150	363·4	205	2561
62	298·1	456	2355	160	368·7	193	2577
63	299·2	449	2359	170	373·6	183	2593
64	300·3	443	2362	180	378·4	174	2608
65	301·3	437	2365	190	382·9	166	2622
66	302·4	431	2369	200	387·3	158	2636
67	303·4	425	2372	210	391·5	151	2650
68	304·4	419	2375	220	395·5	145	2663
69	305·4	414	2378	230	399·4	140	2675
70	306·4	408	2382	240	403·1	134	2687

Having these Tables before us, we shall be enabled to solve, by the common principles of arithmetic, a multitude of practical problems of considerable utility, the investigation of which will further illustrate and familiarise the principles which have been delivered in general terms throughout this article.

By the power of a boiler, I would be understood to mean, in what follows, the number of cubic feet of water which the boiler would evaporate per hour in regular operation.

By the speed of the piston, I mean to express the average number of feet per minute through which the piston is moved.

The engine being understood to be in regular and uniform operation, the total resistance of the piston will be equal to the total pressure of the steam upon it; and the resistance of the piston per square inch of surface will therefore be equal to the pressure of the steam in the cylinder per square inch of surface. These terms, therefore, may be taken as synonymous. In general, the term *pressure of steam* is understood to mean pressure per square inch.

The 3rd column in Table II., which is given as expressing the number of cubic inches of steam of a given pressure produced by the evaporation of a cubic inch of water, will equally express the number of cubic feet of steam produced by a cubic foot of water, or, in general, the ratio of the volume of steam to the volume of water from which it is produced.

QUESTION III.—Given the power of the boiler, the pressure of the steam in the cylinder, and the speed of the piston, to find the diameter.

RULE 3.—In the first column of Table II. find the given pressure; the corresponding number in the third column is the ratio of the volume of such steam to the volume of water which produced it. Multiply the power of the boiler by such number, and the product will be the number of cubic feet of steam per hour which pass through the cylinder, which, divided by 60, gives the number of cubic feet per minute which pass through the cylinder. Divide this by the speed of the piston expressed in feet per minute, and the quotient will be the area of the piston expressed in square feet. Multiply this by 144, and the product will be the area of the piston expressed in square inches. Find this number, or the nearest to it, in the second column of Table I., and the corresponding number in the first column will be the diameter of the piston in inches.

EXAMPLE.—A boiler evaporates 55 cubic feet of water per hour. The pressure of steam in the cylinder is 20 lbs. per square inch. What must be the diameter of the cylinder, so as to give the piston a speed of 200 feet per minute?

By reference to the first column of Table II. we find, opposite the pressure of 20 lbs. in the first column, 1281 in the third column.

Multiply 1281 by 55:

$$\begin{array}{r} 1281 \\ 55 \\ \hline 70455 \end{array}$$

Divide this by 60:

$$\begin{array}{r} 60)70455 \\ \hline 1174{\cdot}25 \end{array}$$

Divide this by 200:

$$\begin{array}{r} 200)1174{\cdot}25 \\ \hline 5{\cdot}8712 \end{array}$$

Multiply this by 144:

$$\begin{array}{r} 5{\cdot}8712 \\ 144 \\ \hline 845{\cdot}4528 \end{array}$$

In the second column of Table I. we find 842·39 opposite $32\frac{3}{4}$ in. or $32\frac{12}{16}$in., and 848·83 opposite $32\frac{7}{8}$ or $32\frac{14}{16}$.

If, then, we take a mean between these, we may assume the diameter of the cylinder required to be $32\frac{13}{16}$ inches.

QUESTION IV.—Given the diameter of the piston in inches, the total resistance it opposes to the moving power, and its speed, to find the power of the boiler.

RULE 4.—Find in the first column of Table I. the given diameter. The corresponding number in the second column will be the area in square inches. Divide

the total resistance of the piston by this number, and the quotient will be the resistance per square inch, or the pressure of the steam. Find this pressure in the first column of Table II., and the corresponding number in the third column will be the ratio of the volume of steam to the volume of water which produces it. The volume of steam will be found by Rule 2. Let this column be divided by the number obtained as above from Table II., and the quotient will be the power of the boiler.

Example.—It is required to find how many cubic feet of water per hour the boiler must evaporate to drive a piston of 34 inches diameter, at the rate of 200 feet per minute, against a gross resistance of 18,000 lbs.

Opposite 34 in the first column of Table I. we find in the second column 907·92.

Divide 18,000 by 907·92 :

$$907{\cdot}92)18000 \over 19{\cdot}8$$

Looking in the first column of Table II., the nearest number to 19·8 is 20, opposite to which, in the third column, we find 1281.

By Rule 1, we find the area of the piston to be in square feet

$$144)907{\cdot}92 \over 6{\cdot}305$$

By Rule 2, multiply this by 200 :

$$\begin{array}{r} 6{\cdot}305 \\ 200 \\ \hline 1261{\cdot} \end{array}$$

Multiply this by 60 :

$$\begin{array}{r} 1261 \\ 60 \\ \hline 75660 \end{array}$$

Divide this by 1281 :

$$1281)75660 \over 59{\cdot}06$$

The boiler must therefore evaporate 59 cubic feet of water per hour.

Question V.—Given the power of the boiler, the diameter of the piston and its speed, to find the pressure of steam upon the piston, or, what is the same, its resistance per square inch.

Rule 5.—By Rules 1 and 2, find the number of cubic feet of steam per hour which pass through the cylinder. Divide this by the power of the boiler, and the quotient will be the number of cubic inches of steam which would be produced by a cubic inch of water. Find this number, or the nearest to it, in the third column of Table II., and the corresponding number in the first column will be the pressure of steam in the cylinder, or the resistance of the piston per square inch.

Example.—What total resistance per square inch will a 35-inch piston, supplied by a boiler evaporating 55 cubic feet an hour, drive at the rate of 200 feet per minute ?

In Rules 1 and 2, we find the number of cubic feet which pass through the cylinder as follows : the diameter of the piston being 35 inches, we find by Table I. that its area is 962·11 square inches ; and by Rule 1, that this is equal to 6·68 square feet. Multiplying this by 200, by Rule 2, it gives the product 1336, which, multiplied by 60, gives 80,160 as the number of cubic feet of steam which pass through the cylinder per hour. Divide this by 55, and we find the quotient 1457 Looking in

the third column of Table II., we find the number 1488 opposite 17, and 1411 opposite 18. Taking a mean between which, we may assume the required pressure to be $17\frac{1}{2}$ lbs. per square inch.

QUESTION VI.—Given the power of the boiler, the pressure of steam in the cylinder, and the diameter of the piston, to find its speed.

RULE 6.—In the first column of Table II. find the given resistance or pressure: the corresponding number in the third column, multiplied by the power of the boiler, will give the number of cubic feet of steam per hour which pass through the cylinder. Divide this by the area of the piston in square feet, found by Rule 1, and the quotient will be the speed of the piston in feet per hour, which, divided by 60, will be the speed of the piston.

EXAMPLE.—With what speed will a 35-inch piston be driven against a resistance of 20 lbs. per square inch by a boiler which evaporates 56 cubic feet of water per hour?

Opposite to 20 in the first column of Table II. we find, in the third column, 1281. Multiply this by 56:

$$\begin{array}{r} 1281 \\ 56 \\ \hline 71736 \end{array}$$

By Rule 1, we find that the area of the piston in square feet is 6·68.

Divide 71736 by 6·68:

$$\begin{array}{r} 6{\cdot}68)\overline{71736} \\ \hline 10739 \end{array}$$

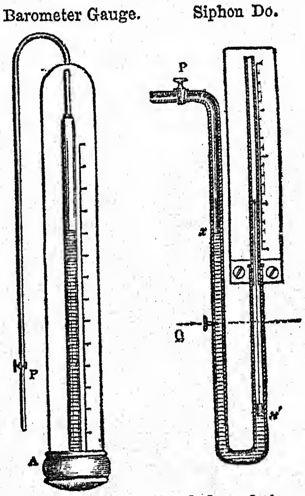
Divide this by 60, and the quotient, 179, very nearly, will be the speed of the piston.

SECTION XXVII.—ILLUSTRATIONS.

The following diagrams and descriptions of the principal parts of steam engines, which have been explained in general terms in the preceding sections, will render the principles which govern the operation and structure of these machines still more clearly and easily understood.

BAROMETER GAUGE.

Barometer Gauge. Siphon Do.



This gauge is constructed in various forms. In the annexed figure the cistern A contains mercury; the barometer tube is immersed in it, and the top of the tube, formed into a siphon, communicates with the condenser; a stop-cock P being placed between them so as to open or close the communication at pleasure.

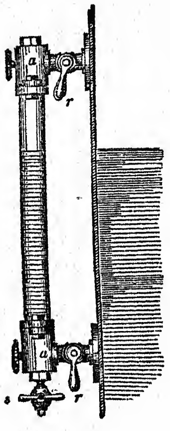
SIPHON BAROMETER GAUGE.

The second figure is another form, in which the barometer is a siphon, like the steam gauge. The tube and stop-cock P communicate with the condenser, and the other leg of the siphon is open to the atmosphere. A hole, stopped by a screw Q, is placed in one of the legs: mercury being poured in at the other leg, the siphon is filled until the mercury begins to flow from the hole Q. The fluid then will stand at the same level in both legs. The hole Q being then

stopped, and the stop-cock P opened, the upper part P Q of the tube will be filled with the uncondensed vapour of the condenser, which will of course press upon the column of mercury in the syphon.

The other leg of the siphon x', being open to the atmosphere, will be subject to the atmospheric pressure; and the column of mercury in the leg P Q, which is above the level x', will represent the excess of the pressure of the atmosphere above the pressure of the uncondensed steam, which is the indication the barometer gauge is required to give.

This siphon being made of iron, a float is placed on the mercury at x', having a rod, at the top of which is an index, which plays upon a scale so graduated as to express the difference of level of the mercury in the two legs of the siphon.



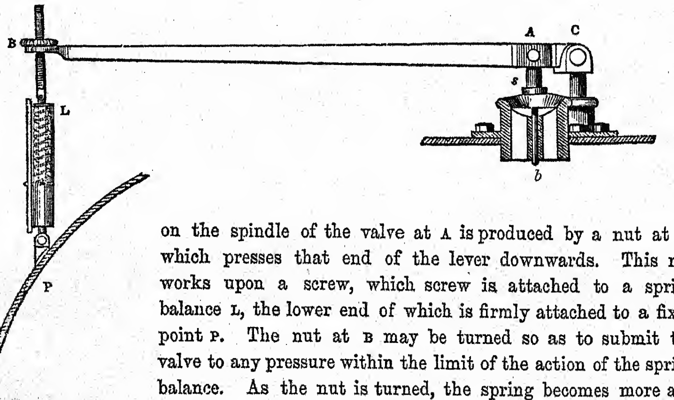
GLASS WATER GAUGE.

In the annexed figure is represented the glass water gauge described in the text. Its communications with the boiler are opened and closed at pleasure by the cocks *r*. When the cocks *r* are both open, the upper end of the tube *a* is in free communication with the upper part of the boiler where steam is contained, and the lower end of the tube *a* is in communication with the lower part of the boiler where water is contained.

Water enters below and steam above, and as the pressure in the gauge tube is the same as the pressure in the boiler, the level of the water in the tube will be the same as the level of the water in the boiler. At the bottom of the tube is placed a stop-cock *s*, for the occasional discharge of water from the tube.

THE SPRING SAFETY-VALVE FOR HIGH-PRESSURE BOILERS.

In the following figure is represented the safety valve, as used in high-pressure engines. The conical valve is represented in its seat, its spindle *s* being pressed down at A by the lever B A C. C is a fixed pivot, on which the lever plays. The pressure



on the spindle of the valve at A is produced by a nut at B, which presses that end of the lever downwards. This nut works upon a screw, which screw is attached to a spring balance L, the lower end of which is firmly attached to a fixed point P. The nut at B may be turned so as to submit the valve to any pressure within the limit of the action of the spring balance. As the nut is turned, the spring becomes more and more compressed. An index and scale are attached to the balance, the scale being so divided as to express the number of pounds per square inch by which the valve is pressed upon its seat. Thus, if the nut B be turned until the index shows the pres-

sure of 50 lbs., then the force on the valve will be at the rate of 50 lbs. per square inch, and the steam will be confined in the boiler until it has attained such pressure: when the pressure exceeds that limit, the lever at B will, by the action of the steam on the valve, press the nut upwards with a force greater than the energy of the spring, and the spring will consequently be further compressed, the valve at the same time opening and allowing the escape of the steam.

There is nothing in the principle of this valve essentially different from the common safety valve, directly loaded with a weight; but in boilers where high pressures are used, the quantity of weight which it would be necessary to place on the valve would be inconvenient. A comparatively small force, holding B downwards, will produce a multiplied effect at A, in the proportion of the length of the lever B C to A C. Thus, if B C be 20 times A C, a force of 5 lbs. at B will produce 100 lbs. at A.

WATT'S INDICATOR.

This little instrument, already described in the text, will be rendered more intelligible by the annexed diagram; fig. 1 representing a front view in section, and fig. 2 a side elevation. The rod attached to the piston plays through a collar at *a*. At *t* is a pencil-holder. At *s* is a screw by which the instrument is inserted in a hole provided for it in the top of the cylinder. At *d* is a stop-cock, by which a communication may be opened or shut at pleasure between the indicator and the cylinder. The piston-rod of the indicator is surrounded by a spiral spring, the lower extremity of which is attached to the piston and the upper extremity to a fixed piece *a*, containing the hole through which the piston-rod plays. When the piston rises, the spring is compressed; and when it falls, the spring is extended. The spring is *in equilibrio* when the piston is at the middle of the cylinder, and the space through which it rises and falls is, from the known properties of this species of spring, proportional to the force which presses the piston upwards or downwards. When both extremities of the cylinder are open to the atmosphere, the spring is at rest, and the piston in the middle of the cylinder; but when steam is allowed to pass from the cylinder to the indicator, by opening the stop-cock *d*, such steam will press the piston upwards, and compress the spring with a force equal to the excess of the pressure of the steam above that of the atmosphere. When, on the other hand, a vacuum is produced in the cylinder by the condensation of the steam, the same vacuum will be produced under the piston in the indicator, and the piston will be forced downwards by the excess of the pressure of the atmosphere above that of the uncondensed vapour in the cylinder.

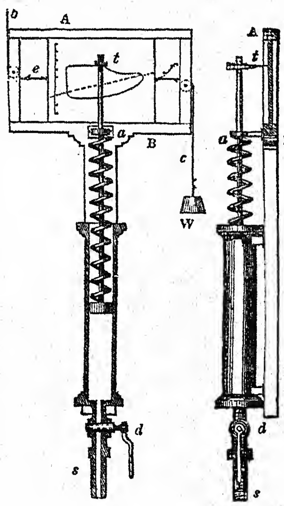


Fig. 1. Fig. 2.

If an index were placed near the extremity of the piston-rod *t*, the pencil, ascending and descending on this index, would indicate by the space through which it would ascend the excess of the pressure of the steam over that of the atmosphere, and by the space through which it would descend the excess of the pressure of the atmosphere over that of the uncondensed vapour. Both spaces added together, or the entire play of the piston, would therefore indicate the excess of the pressure of

the steam above the pressure of the uncondensed vapour which resists it, and would therefore indicate the effective force of the piston, exclusive of friction.

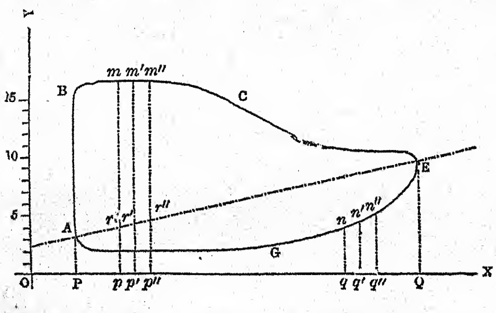
But as the piston of the indicator would be in rapid and continued motion, it would not be easy to observe and record the limits of its play, and still more difficult to note the rapidity of its motion. An ingenious expedient was therefore contrived to enable the engine itself to record these effects, which converted the indicator into a self-registering instrument. A small square frame A B was constructed, the breadth of which was somewhat greater than the extreme play of the piston of the indicator. In it was placed a card, capable of sliding in a horizontal direction in grooves: a string *e* was fastened to the side of the card, and passing under a pulley, was carried upwards towards *b*, and attached to some part of the machinery which rises and falls with the piston of the engine. Another string *f* was attached to the other side of the card, and carried over a pulley and fixed to a small weight W. When the piston rises, the string *e* is drawn to the left, the card drawn in the same direction, and the weight W rises. When the piston falls, the weight W, acting on the string *f*, draws the card to the right.

Thus, as the piston rises and falls, the card is drawn alternately through a certain space left and right.

Let us now suppose steam admitted above the piston of the engine, pressing the piston down; this steam presses the piston of the indicator up, and the pencil *t*, passing on the card, would, if the card were at rest, mark upon it a straight line, the length of which would indicate the pressure of the steam; but as the card is drawn from left to right while the piston falls, the piston will describe upon it a curve by the combined effects of the vertical motion of the pencil and the horizontal motion of the card. The suddenness of the curvature thus described will indicate the rapidity of the action of the steam on the piston.

When the piston has reached the bottom of the cylinder, and the upper exhausting valve is opened, a vacuum is produced in the cylinder, which vacuum extends to the indicator, the piston of which therefore descends, the pencil *t* descending at the same time and at the same rate. While this takes place the card is moved from right to left, and a corresponding curve described upon it by the pencil, the curvature of which will indicate the suddenness with which the vacuum is produced, as well as its degree of perfection.

From what has been stated it will appear, that in a single ascent and descent of the piston, or in one stroke, as it is technically called, a diagram will be formed upon the card, which will exhibit not only the entire mechanical effect of the steam acting on one side against the uncondensed vapour on the other, but will shew the entire character of its progressive action at every point of the stroke. Such a diagram is exhibited in the annexed figure.



Let O X be a horizontal line. Let O Y be the vertical scale which measures the pressure of the steam according to the movement of the indicator. Let O be the level to which the pencil would be depressed, if there were a perfect vacuum in the cylinder; then the height of the pencil at any moment above

the level of the horizontal line O X will indicate the absolute pressure of the steam in the cylinder, independently of any consideration of the pressure of the atmosphere. Let A be the position of the pencil at the moment steam is admitted above the piston. By the action of the steam the pencil will suddenly start up to B, and after the piston has commenced its action, it will rise a little higher, the card meanwhile being drawn to the left. The line will be traced on the card by these means, as represented at B $m\,m'$ and m''. As the piston approaches the bottom of the cylinder, if the steam be cut off before the completion of the stroke, the pressure will diminish, and from C to E the pencil will fall. Let E be its position at the end of the stroke, the card being understood to be moved from right to left through the space P Q during the stroke. We may consider this motion of the card as representing the motion of the piston, with which it is simultaneous and proportionate. At the commencement of the stroke, the height A P of the pencil above O X represents the pressure of the uncondensed vapour which was then above the piston; the height B P represents the pressure of the steam immediately on its admission; the height $m\,p$ represents its nearly uniform pressure throughout the former half of the stroke; and the decreasing height of the curve from C to E, above the line O X, represents the decreasing pressure of the steam throughout the remainder of the stroke. E Q represents the pressure of the steam at the termination of the stroke.

The piston now commences its ascent. The upper exhausting valve being opened, and the steam allowed to flow to the condenser, according as it is condensed a vacuum is formed while the piston is rising, and while the card is moved back from left to right under the pencil. Starting from E, the pencil begins to fall, and falls more and more as the vacuum becomes more perfect. At G the vacuum attains its most perfect state, and the line from G towards A continues nearly horizontal, its height above O X representing the nearly uniform pressure of the uncondensed steam; but just before the termination of the stroke the steam is admitted from the boiler, and the pencil rises to A. The height of the curve E G A at every point represents the varying pressure of the uncondensed vapour which resists the ascent of the piston.

Now although that portion of the curve below the line A E represents the state of the vacuum above the piston during its ascent, it may be taken to represent the state of the vacuum below the piston in its descent, for the same circumstances which affect one equally affect the other; and we may consider the diagram generally as representing not only the pressure of the steam which urges the piston downwards, but also that of the uncondensed vapour which resists its descent.

It appears then that the varying heights of the points of the upper curve B C E represent the varying pressures on the piston during its descent; and the average pressure upon the piston may be obtained by taking the average of these heights.

In like manner, the heights of the lower curve A G E may be taken to represent the varying pressures or resistances of the uncondensed vapour under the piston during its descent; and the average of all these heights will give the average of such resistances. If then we subtract the average of these resistances, represented by the lower curve, from the average of the pressures represented by the upper curve, we shall obtain the effective pressure of the steam in urging the piston.

However accurately such an instrument as this may be constructed, it must be admitted that it cannot be depended on as affording any exact measure of the power of the piston. Its chief value, as stated in the text, is the indication it affords of the degree of perfection of the vacuum and of the suddenness of its formation. The curve E G should fall to its least height speedily. It is not until it attains its least height

that the vacuum has attained its greatest perfection. For the rest, the use of the instrument is sufficiently explained in the text.

THE SLIDE VALVES.

In the annexed figures are represented forms of slide valves.

Fig. 1. Fig. 2. Fig. 3.

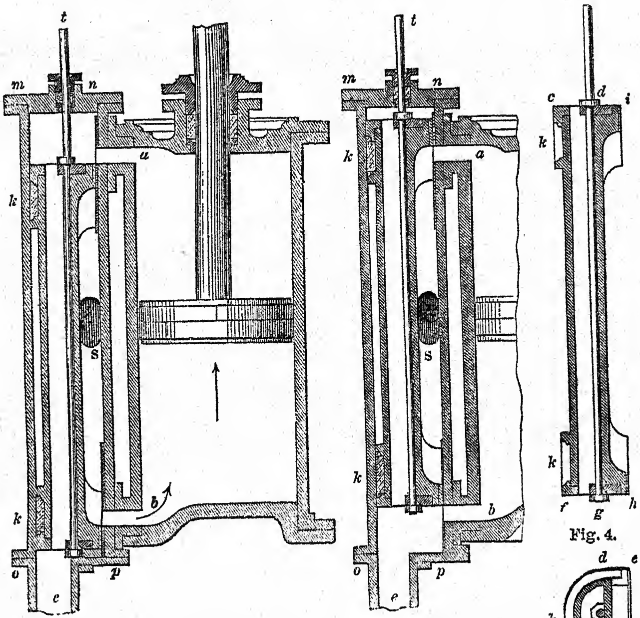


Fig. 4.

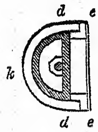


Fig. 1 represents in section the cylinder, piston, and slide : S is the mouth of the steam pipe, coming from the boiler; *e* is the pipe leading to the condenser; *t* is the rod which is attached to the slide, moving through a stuffing-box *m n*. This slide is represented in longitudinal section, separately, in fig. 3, and in transverse section in fig. 4. In the position of the slide represented in fig. 1, the steam passing from the boiler enters at S, and passes to the bottom of the cylinder through the opening *b*, and acts below the piston, causing it to ascend. The steam which was above the piston escapes through the opening at *a*, and descending through a longitudinal opening in the slide behind the mouth of the steam pipe, finds its way to the pipe *e*, and through that to the condenser.

When the piston has reached the top of the cylinder, the slide will have been moved to the position represented in fig. 2. The steam now entering at S passes through the opening *a* into the cylinder above the piston, while the steam which was below it escapes through the opening *b* and the pipe *e* to the condenser.

The form of the valve, from which it derives its name of D-valve, is represented in fig. 4. The longitudinal opening through which the steam descends then appears in section of a semicircular form. The packing at the back of the slide is represented at *k*; this is pressed against the surface of the valve box.

STEAM ENGINE, LOCOMOTIVE.*

SECTION I.—RELATION BETWEEN THE WEIGHT OF FUEL AND THE HEAT WHICH IT GENERATES.

The problem of measuring the heat evolved in the combination of bodies is one of essential importance in connection with many of the arts of life, and has accordingly received the attention of distinguished scientific men. Count Rumford, Crawford, Watt, Black, Lavoisier, Dalton, M. Despretz, M. Dulong, M. Hess, M. Arago, Berzelius, Dr. Ure, are amongst the names of those who have devoted themselves to the inquiry. The results of the earlier experiments must be regarded as approximations towards the more precise data which have been within the last few years obtained; and the conclusions derived by the first labourers in this branch of science have consequently undergone considerable modification.

The experiments of M. Dulong, and of others subsequently, especially those of M. Hess, and of Dr. Andrews of Belfast, appear to have been conducted with the greatest accuracy, and with those precautions, as regards the arrangement of the apparatus, the mode of manipulation, and the reduction of the observations, which are indispensable to insure correct and consistent results.

These experiments may be considered as establishing the following general conclusions.†

The quantity of heat disengaged by different substances is very different.

Hydrogen, for instance, produces about four times the heat derived from an equal weight of carbon, and fourteen times the heat from an equal weight of sulphur, in the act of combining with oxygen. The observations of the earlier inquirers, including some by Despretz, indicated a constant relation between the weight of oxygen which entered into combination with the burning fuel and the heat that was evolved; in other words, that a pound of oxygen would generate in each case the same quantity of heat, whether in combining with hydrogen, carbon, alcohol, ether, or other combustibles. This conclusion, which would not be inconsistent with the law expressed, inasmuch as the combining proportions of oxygen and combustible bodies differ greatly for different bodies, is, however, not supported by later experiments.

The quantities of heat evolved are (nearly) the same for the same substance, no matter at what temperature it burns.

From this law it follows, that the *rate* at which combustion may proceed does not affect the quantity of heat produced by a given weight of fuel. The rate of combustion is proportional to the temperature excited and to the supply of oxygen delivered.

A pound of carbon generates precisely the same quantity of heat, whether it is burnt with rapidity in an intensely heated furnance, under the influence of a powerful blast, or whether it is consumed slowly in an Arnott's stove, wherein the supply of oxygen is purposely limited, in order to moderate the intensity of the heat, and prolong the duration of the effect.

Some engineers have believed that the greatest economy in fuel is obtained in cases of very slow combustion, and this mode of applying heat has been adopted with apparent advantage in the so-called "Cornish boilers;" but if the fact be so, for which reasonable doubt exists, the cause is owing partly to the retention of the heat for a

* Extracted from "Observations on the Consumption of Fuel and the Evaporation of Water in Locomotive and other Steam Engines." By Edward Woods, Esq., C.E.

† See "Phil. Mag.," July, 1841: "Summary of Discoveries on the Heating Powers of Bodies."

longer time in the spaces around the boiler, and thereby increasing the ratio of the heat absorbed by the boiler to the heat which escapes up the chimney; and partly, perhaps, also, with certain descriptions of coal, to their inability to withstand an intense heat very suddenly applied, without undergoing a change of form which is unfavourable to a complete combustion.

The quantities of heat evolved by carbon and hydrogen, as ascertained by Dr. Andrews,* whose results accord very closely with those of M. Dulong, are as follows:

1 gramme carbon evolves		7900	(French) units of heat.
1 do.	hydrogen ,,	33808	ditto.

The unit they adopt is the amount of heat required to raise, through one degree centigrade, one gramme of water at the temperature at which the experiment is performed.†

Reducing the results to English weights and measures, and taking the unit as the amount of heat required to raise through one degree Fahrenheit one avoirdupois pound of water at the temperature of the experiments, we find that in combining with oxygen

1 pound of carbon	evolves	14220	(English) units of heat.
1 do. of hydrogen	,,	60854	ditto.

These amounts of heat, applied to the evaporation of water already raised to the temperature of 212° Fahrenheit, assuming that the latent heat of steam of the same temperature is 972°, would produce the following effects:

1 pound of carbon	will evaporate	14·6	pounds water from 212° Fahr.
1 do. of hydrogen	,,	62·6	do.‡

These numbers may be therefore taken to express the highest§ duty which the above-named elementary substances, in their purest state, can possibly accomplish, supposing the entire heat disengaged to be communicated to the water, and none lost by external radiation and conduction.

The duty expressed by the above numbers we shall term the "theoretical" duty of the fuel in evolving heat, not using the word to denote an effect not yet ascertained in fact, but by way of contrast to the effective working duty of fuel as used in common practice.

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* "Phil. Mag." Aug. Sept. 1844.

† *Table of Results of Dr. Andrews' Experiments on other Substances.* ("*Phil. Mag.*" *Aug. Sept.* 1844.

1	gramme	carbonic oxide	evolves	2431	units of heat.
1	do.	marsh gas	,,	13108	do.
1	do.	olefiant gas	,,	11942	do.
1	do.	alcohol (sp. gr. 0·7959) at 59° Fahrenheit	,,	6850	do.
1	do.	sulphur	,,	2307	do.
1	do.	phosphorus	,,	5747	do.
1	do.	zinc	,,	1301	do.

1 gramme (French) = ·00220606 lbs. avoirdupois.
100 degrees centigrade = 180 degrees Fahrenheit.

‡ 14220 units ÷ 972° = 14·6.
60854 do. ÷ 972° = 62·6.

§ The second measure of heat, here adopted, is a common and convenient one; but it may be necessary to explain that it supposes the heat imparted to the water to be directly and entirely carried off in the steam and lost, and by no means involves the proposition, that under certain other circumstances,—as for instance when the heat of steam evaporated in one stage of the process is applied to the evaporation of water in a subsequent stage,—the duty of fuel cannot be increased beyond the numbers here given.

It is almost superfluous to state, that the necessary conditions for obtaining the "theoretical" duty, as regards the purity of the fuel and the prevention of extraneous dispersion of heat, can only be fulfilled approximately; but it is nevertheless important to know the ultimate limit of duty, in order to be able to compare it with the actual working duty in each case of the application of fuel in the furnace. The difference will render manifest the amount by which the working duty falls short of the theoretical, and the proportion between the one and the other will be the true measure of the degree of perfection attained in any given boiler and furnace.

The heat evolved in the combustion of certain of the compound gases is the same (nearly) as that evolved in the combustion of their constituents separately.

This law* holds good in regard to the gases compounded of carbon and hydrogen. Such, in fact, are the gases distilled from bituminous coal when exposed to a red heat. Let us apply the law to the cases of light carburetted hydrogen and olefiant gas.

Light carburetted hydrogen is composed of

Carbon	1	equivalent; weight	= 6·12
Hydrogen	2	do. do.	= 2·00
Light carb. hydrogen . . .	1	equivalent; weight	= 8·12

Supposing the elements to be burnt separately,

The carbon would produce	48348	units heat	= 7900 × 6·12
The hydrogen ,,	67616	do.	= 33808 × 2
	115964	do.	

which number, divided by the weight 8·12, gives a quotient of 14281 units of heat for each gramme of the compound.

The heat resulting from the combustion of light carburetted hydrogen is in fact (see Table, page 486) 13108 units.

In the case of olefiant gas the agreement is closer. Olefiant gas is composed of

Carbon	4	equivalents;	weight	24·48
Hydrogen	4	do.	do.	4·00
Olefiant gas	1	do.	do.	28·48

Supposing the elements to be burnt separately,

The carbon would produce	193392	units of heat.
The hydrogen ,,	135232	do.
	328624	do.

which number, divided by the weight 28·48, gives a quotient of 11539 units of heat for each gramme of the compound.

The combustion of 1 gramme of olefiant gas produces (see Table, page 486) 11942 units of heat.

From the above considerations it would at first sight appear probable that the heating duty of fuel is equal (nearly) to the sum of the separate duties of its constituent combustible elements, supposing these to be fully oxidised; and that when the composition of any given coal or coke is known, its theoretical value in generating heat could be assigned accordingly. But it so happens that the elements out of which the gaseous combustible products of coal are formed exist in coal in the solid state,

* The correspondence may be conceived to be the closest when the constituent gases, in combining, neither set free nor bind any heat.

and require for their conversion into the gaseous state, and before they are in the condition themselves to burn and evolve heat, a large quantity of heat derived from the previous combustion of other parts of the fuel. The quantity of heat thus abstracted has never been accurately ascertained, but is supposed, on a rough computation, to amount to little less than the heat afterwards evolved in the combustion of the gas. It has accordingly been often remarked that those coals which contain the least gas are practically the strongest.

In the absence of direct experiment, we are perhaps not justified in assuming that the heating value of any description of coal containing hydrogen exceeds that of the carbon it contains.

Upon this assumption, the following rule for the heating value of fuel will apply:

Multiply the weight (in lbs.) of carbon in the fuel by 14·6, and divide the product by the weight of the fuel in lbs.: the quotient is the theoretical heating power of 1 lb. of the fuel.

Thus, for instance, to take the best Newcastle caking coal, which on an average of specimens was found by Mr. Richardson (see "Phil. Mag." 1838, vol. xiii. p. 121).

88·0	carbon.
5·2	hydrogen.
5·4	azote and oxygen.
1·4	ashes.
100·0	

$$\text{Carbon } 88 \times 14{\cdot}6 = 1284{\cdot}8$$

Theoretical duty of 1 lb. of dry coal is equal to 12·84 lbs. water evaporated from 212° Fahrenheit.

When it is considered that even in the same mines the quality of the coal varies materially, and that, comparing the bituminous coals obtained from different mines, the proportion of carbon ranges from 60, or even less, to 88 per cent., and the quantity of ashes from 1 to 15 per cent. and upwards, it is obvious that no constant expression of the value can be assumed, but that it is necessary in each case to ascertain the specific composition and assign the duty.

We shall hereafter inquire how far the theoretical and working duties differ, and explain some of the causes of the difference.

Relation between Mechanical Force and the Heat which produces it.

One of the most important and interesting inquiries relative to the steam engine is that which traces the connection between the heat expended and the force produced.

The method of separate condensation discovered by Watt,—the application by Woolf and Hornblower of the force of expanding steam,—occasioned an important change in the relation of heat to power, and increased in a remarkable manner the dynamical value of fuel.

There are no sufficient grounds for concluding that the improvements in the steam engine subsequently made, and extending even down to the present time, have reached the highest point of the scale. On the contrary, there is strong evidence of the existence of a margin in the field of economy, in the working duty of fuel, ample enough to occupy the husbandry of many labourers for some time to come, and holding out the prospect of a good return.

The recent inquiries of some scientific men, whose attention has been engaged on the subject of the relation between heat and the mechanical effects it produces, have resulted in the discovery of the principle, that the *action of a given amount of heat*

may be represented by a constant mechanical work performed; that is to say, by the elevation of a determinate weight through a determinate height.

This constant of work for the unit of heat has been termed '*the mechanical equivalent of heat,*' and expresses the maximum limit of duty which, on the assumption of the truth of the above-named principle, that unit of heat can possibly perform.

It has been shown that, through whatever medium or carrier the mechanical work of heat may be developed or conveyed, whether by means of the vapour of water or other liquids, or by means of atmospheric air or other gaseous matter, the same amount of work is invariably the result.

This constant of work is many times greater than the work hitherto obtained from the best condensing expansive engines.

M. Clapeyron, in his treatise on the moving power of heat, and M. Holtzmann of Manheim, who availed himself of the labours of M. Clapeyron and M. Carnot in the same field, grounding their investigations on the received laws of Boyle or Mariotte, and Gay-Lussac, which express the observed relation of heat, tension, and volume in steam and other gaseous matter, have by theoretical inquiry arrived at the conclusion that—

The mechanical equivalent of the quantity of heat capable of increasing the temperature of 1 lb. of water by one degree of Fahrenheit's scale is a mechanical force capable of raising a weight between the limits of 626 lbs. and 782 lbs. one foot high.

Mr. Joule, of Manchester, proceeding by entirely different, and independent, and in fact purely experimental methods, concludes that the mechanical equivalent of heat may be taken at 782 lbs. raised one foot.

The mode of investigation pursued by the continental philosophers, especially by M. Holtzmann,* may be thus briefly explained.

They suppose a given weight of steam, or gaseous matter, to be contained in a vertical cylinder formed of non-conducting material, in which is fitted an air-tight but freely moving piston. This piston is pressed downwards by a weight equal to the pressure or tension of the steam or gas. The weight, initial temperature, pressure, and volume being known, a definite quantity of heat from without is supposed to be imparted to the vapour.

The result will be partly an elevation of the temperature of the vapour, and partly an increase of volume, or, in other words, a motion of matter, the pressure or tension remaining the same.

But the result may be represented simply and solely by a motion of the matter (dilatation). For this purpose it is only necessary to allow the vapour to dilate without any loss of its original or imparted heat until it re-acquires its initial temperature.

In this case the final effect is simply dilatation of the vapour under the subsisting pressure; and the mechanical work done is represented by the product of that pressure into the space through which it has been made to recede.

Mr. Joule's estimate of the mechanical equivalent of heat is derived from three distinct classes of experiments.

1st. From the calorific effects of magneto-electricity. ('Phil. Mag.' 1843, vol. xxiii. p. 263.)

This method is to revolve a small compound electro-magnet, immersed in a glass

* 'Über die Wärme und Elasticität der Gase und Dämpfen.' Von C. Holtzmann. Manheim, 1845.

vessel containing water, between the poles of a powerful magnet; to measure the electricity thence arising by an accurate galvanometer; to ascertain the calorific effect of the coil of the electro-magnet by the change of temperature in the water surrounding it. Heat is proved to be *generated* by the machine, and its mechanical effect is measured by the motion of such weights as by their descent are sufficient to keep the machine in motion at any assigned velocity.

2ndly. From the changes of temperature produced by the rarefaction and condensation of air. ('Phil. Mag.,' 1845, vol. xxvi., p. 369.)

In this case, the mechanical force producing compression being known, the heat resulting was measured by observing the changes of temperature of the water in which the condensing apparatus was immersed.

3rdly. From the heat evolved by the friction of fluids. ('Phil. Mag.,' 1847, vol. xxxi., p. 173.)

A brass paddle-wheel, in a copper can containing the fluid, was made to revolve by descending weights. Sperm oil and water as the fluids gave the same results.

The mechanical equivalent of the unit of heat was—

As assigned by the	1st method,	838 lbs.	raised 1 foot.
,,	2nd	do.	795 lbs.	do.
,,	3rd	do.	782 lbs.	do.

Mr. Joule considers the last method as likely to give a more accurate result than either of the two former; and it is remarkable that the equivalent given by the third method, viz., 782 lbs., should be identical with the major limit assigned by Holtzmann.

We shall, however, prefer to take the mean adopted by Holtzmann, and to consider *the mechanical equivalent of the unit of heat* as represented by a *weight of* 682 lbs. *lifted one foot high;* the unit of heat being the quantity required to raise the temperature of a pound avoirdupois of water one degree Fahrenheit.

The Working Duty of Fuel as regards the Production of Steam.

It has been shewn that the amounts of heat obtainable from carbon and hydrogen respectively are such as in the case of the combustion of

1 lb. of carbon would suffice to evaporate 14·6 lbs. of water from 212°;

and in that of the combustion of

1 lb. of hydrogen would suffice to evaporate 62·6 lbs. of water from 212°;

but that the effect of any heat given out by the combustion of the hydrogen is in great measure neutralised by the absorption of heat necessary to volatilise the hydrogen and it has been observed that such results are not attainable in practice, in consequence of the diversion of the heat evolved into other channels than those which conduct it directly into the water. To this may be added, that in the common instances o so-called combustion, the combustion is only partial, a portion of the fuel being dissipated without undergoing combustion at all.

Whatever difference may be found practically to exist between the actual and the theoretical duty of the fuel consumed under any given boiler, or given system of firing, may be assigned to one or other of the above causes; and in the comparison of different boilers or modes of firing, the *amounts* of difference, as expressed by the *ratios* between the actual and theoretical duties, would constitute a scale by which the commercial value of any particular apparatus or system of firing can be tested.

In the *Cornish boiler* a duty equal to 10·29 lbs.* water, evaporated from the temperature of 212°, has been obtained from 1 lb. of coal.

* Report on the Coals suited to the Steam Navy. By Sir H. De La Beche and Dr. Lyon Playfair.

In the *cylindrical* boilers used in the manufacturing district of Manchester, the duty does not appear to exceed 7 lbs. water evaporated from 212° by 1 lb. of coal.

In the *locomotive* boiler it has been found, on the average of an extensive series of experiments on the engines of the Liverpool and Manchester Railway, that the duty of 1 lb. of Hulton or Worsley coke is equal to the evaporation of $8\frac{1}{2}$ lbs. water from the temperature of 212°.

In the larger engines of the Great Western Railway nearly the same duty is obtained. Mr. Gooch* states that their last-constructed engines (the area or tube surface being from ten to eleven times the area of the fire-box) evaporate 8 to $9\frac{1}{2}$ lbs. of water with 1 lb. of coke, according to the rapidity of evaporation; the slowest evaporation with a given sized boiler producing the best result.

The variation in the heating quality of different descriptions of coke from different mines is often very great. In Lancashire the Hulton and Worsley cokes rank highest. Representing the duty of these by 100, it was found by trial that the duty of cokes from six other mines was represented by the following numbers: $76\frac{3}{10}$, $80\frac{3}{10}$, $80\frac{3}{10}$, $81\frac{7}{10}$, 89, $90\frac{1}{10}$. In some instances the inferior duty was partly occasioned by the tenderness of the coke or inability to withstand the action of the blast; the large pieces breaking up into small ones, and these either falling through the bars or being carried off by the draft.

The above general results in the three most important classes of steam engine boilers will serve to shew that considerable loss of heat takes place in each case. It does not, however, appear likely that the locomotive boiler can be pushed to perform a much higher duty, taking into account the mechanical limits imposed in its construction. But there is no sufficient reason, except in so far as the comparative cost of alterations and that of anticipated saving in fuel may influence the owner of the boiler in incurring an immediate expense, why the performances of the majority of stationary engine boilers should not be materially improved.

We proceed to consider briefly the circumstances which occasion a diversion of a portion of the heat generated, and dissipation of part of the fuel unconsumed.

Diversion of Heat generated.

This may be ascribed chiefly to one or other of the following causes:—

1. *Vaporisation of the hygrometric water.*

Coal, in the state in which it is obtained from the mine, contains from 1 to 2 per cent. of water: when exposed to the atmosphere, and especially to rain, it of course imbibes a further quantity, which is greater or less in proportion to the moisture of the air and to the size of the particles of coal; the smaller kinds, and especially what is termed 'slack,' being more retentive than the round coal. This water must be converted into vapour before combustion takes place, and the heat necessary for its conversion must be derived from other portions of fuel undergoing combustion, and is consequently not communicated to the boiler.

Coke, being of a much more porous or spongy texture than coal, absorbs frequently as much as 7 per cent. of water in its passage from the oven to the place of consumption in uncovered waggons. A difference in the hygrometric state of the atmosphere has a marked and rapid effect on the amount of hygrometric moisture in coke. Upon accurate weighing it was found that a quantity of coke delivered in rainy weather, and afterwards exposed for a few days to a drying wind, was reduced from 388 cwt. to 360 cwt. Hence will be seen the advantage of keeping the coke dry until the time

* 'Report of Commissioners of Railways respecting Railway Communication between London and Birmingham,' 1848, p. 57.

it is actually put into the furnace; for not only is there in damp fuel a less quantity of combustible matter than is paid for, unless due allowance be expressly made, but there is a positive reduction of effective power in the combustible portion itself.

Thus, to take the instance cited of coke with 7 per cent. of moisture:

100 lbs. of such coke contains 93 lbs. dry fuel, and 7 lbs. water = 100.

The 93 lbs. dry coke are competent in practice to evaporate $8\frac{1}{2}$ times its weight of water . . . . = 790 lbs.

But 7 lbs. water contained in the fuel must first be evaporated . . = 7 lbs.

There remains, therefore, as the effective quantity of water evaporated by 100 lbs. of damp fuel . . . . = 783 lbs.

Whereas 100 lbs. dry coke evaporate 850 lbs. water.

This is equal to a diminution of effective duty in the proportion of 850 to 783, or about 8 per cent.

In every contract for the supply of coke it is advisable that the contractor should be bound to send it in closed waggons, or waggons covered with water-proof sheets; and the coke dépôts should be so constructed that the waggons may be unsheeted, and the coke weighed out and stocked under cover.

2. *Production of such elevation of the temperature of the air or gases in the chimney as may be required to obtain the draft.*

In the fixed engine furnace the necessary draft is maintained by the differential pressure, as between a column of heated and rarefied air in the chimney-stalk and a column of the colder air without, of equal area and height; the difference of temperature being maintained by the constant accession of heated gaseous matter to the contents of the chimney, which are constantly discharging themselves from the top. It should be the object to render this loss of heat a minimum. The quantity of heat carried off is directly proportional to the quantity of gaseous matter which escapes from the flue into the chimney, and to the temperature at which it escapes. The quantity is a minimum when, for the combustion of any given weight of fuel, no more air has been allowed to pass through the furnace than suffices fully to oxidise the elements of the fuel; and the temperature is a minimum when it does not exceed, unless by a few degrees, the temperature at which the water is being converted into steam of the assigned pressure. When the fire is contained in a box surrounded by water to be heated, as in a locomotive engine, the grate-bar frame should be made to fit closely to the sides of the box; otherwise the surface of the plates adjoining will be insulated from the action of the fire by a stream of cold air rushing upwards between the frame and the box,—a frequent source of waste of fuel.

In the case of the locomotive engine, the draft is obtained mechanically by the application of the steam already generated; and its intensity is liable to considerable variation under differences of pressure in the cylinders, and differences of velocity of the piston.

The current of heated air through the tubes may be made to become so rapid as not to afford the necessary *time* for imparting all the heat which under a milder draft would be taken up by the absorbent surfaces, and a quantity of surplus heat is carried to waste up the chimney.

In former years the draft in the locomotive engine was solely obtained by the action of the blast-pipe. The introduction of the 'close ash-pan,' that is to say, an ash-pan closed below and on all sides except the front,—the front being left open to receive a rush of air produced by the velocity of the train,—has had the effect of relieving the blast-pipe from a part of its duty, and of saving steam and fuel to that extent. It is,

however, to be observed, that the saving is less on lines of undulating gradients than on those in which a *constant* tension on the fire is needed; for whilst the engine is descending a gradient with steam cut off, it is obviously desirable to stop the passage of air through the fire; but the present form of ash-pan prevents this from being entirely done, and there is a certain waste of fuel on descending gradients to set against the saving on other parts of the road where artificial power is required. The remedy would be to have some ready and simple means of controlling the admission of air: if such means were provided, both before and behind the ash-pan, the engine would generate steam equally well, whether running backwards or forwards.

3. *Conduction through solids composing the furnace and boiler, and radiation from the same.*

The greater economy of fuel obtained in the Cornish boilers appears in great measure to arise from close attention to this point; these boilers and furnaces being, in fact, buried in a mass of badly conducting material, such as ashes, brickwork, &c.

The locomotive boiler is particularly exposed to loss of heat from this cause, almost every part being in rapid motion through and in constant contact with the atmosphere, a thin layer of imperfectly-conducting material only intervening. It is usual to clothe the boilers with a layer of felt, then with boards, and over them a thin casing of zinc or oil-cloth stretched tightly, painted and varnished to turn off the wet. The high temperature of the steam acting through the boiler-plate often converts the felt or inner surface of the wooden boards into charcoal, which is a still inferior conductor. Notwithstanding these precautions, there is some radiation and waste of heat.

In outside-cylinder engines, the cylinders are unavoidably placed in a position calculated to cool their surfaces, and diminish the pressure of the steam within, in which respect they work to some disadvantage as compared with inside-cylinder engines, which have their cylinders enclosed in the hot smoke-box.

4. *Dispersion of heated water by priming and leakage.*

This water, suspended mechanically in the steam, and passing with it by the force of the current along the pipes and through the cylinders, without producing any dynamical effect, abstracts as much heat as was expended in raising its temperature from that of the feed-water to the temperature of the issuing steam. The quantity of water and consequently of heat thus carried off is dependent chiefly on the incidental circumstances of the purity of the water used, that is to say, its freedom from mud or greasy matter, and of the steam room given above the surface of the boiling water. The steam room in locomotive boilers being necessarily somewhat more contracted than in fixed engine boilers, and the rate of evaporation in respect of the size of the boiler being much greater, there is more tendency to loss of heat from this source.

The best preventive of this loss consists in properly blowing off and cleansing the boilers at prescribed intervals, and in attention to the purity of the feed-water supplied. With these precautions, the loss in a well-constructed boiler, with properly arranged steam dome and steam pipes, becomes very trifling and scarcely appreciable.

Leakages in boilers are often occasioned by the unequal expansion of parts unequally heated, or of parts formed of different metals whose rate of expansion under equal increments of temperature differs; and such leakages are apt especially to occur after sudden and great variations of temperature, as in boilers after being blown off. Instances are well known in which from such causes a whole set of tubes has suddenly begun to leak.

Dissipation of unconsumed Fuel.

In every furnace a certain amount of heat is lost in two ways; first, by an absolute loss of unburnt substance of the fuel, which may be termed a mechanical loss, inasmuch

as it proceeds from circumstances connected with the physical condition of the coal, or from imperfection in the mechanical apparatus of the furnace; and, secondly, by the incomplete combustion of the elements into which the fuel has been resolved by heat. The latter has its origin in the want of due regard to the chemical relations of the combining elements.

1. *Mechanical dissipation of the fuel.*

Amongst the ashes which fall from the grate-bars of a furnace there is always present a quantity of unconsumed solid fuel. The quantity depends, other things being equal, on the practical relation between the total area of air spaces and the width between the bars. The area of fire-grate being given, the bars must be arranged so as to present the least possible impediment to the passage of air through the fuel, whilst at the same time they afford effectual support even to the smaller pieces. For this reason it is desirable to make the grate-bars as thin as the strength or durability of the material (cast or wrought iron) will allow, adding in depth to make up for deficiency in thickness. The spaces between the bars are adapted to the nature of the fuel. In the case of small coal and slack the spaces must be more contracted than where rounder coal or coke is employed. Experience soon shows what is the best proportion.

For the best qualities of coke, in the locomotive furnace, the following proportions have been found, on the Liverpool and Manchester Railway, to work with the best effect:

Thickness of bars	$\frac{1}{2}$ inch.
Width of air spaces	1 do.

With these dimensions, the proportion borne by the entire area of air spaces to that of grate surface is as 67 : 100.

The thinner the bars, the more will the proportion be increased. Probably a bar less than $\frac{1}{2}$ an inch thick could not be made durable.* About $\frac{3}{4}$-inch is a common thickness for locomotive furnaces. With such bars, and 1-inch spaces between, the proportion of air space to total area of grate surface is as 57 to 100, shewing a reduction of 10 per cent. of air space as between $\frac{1}{2}$-inch and $\frac{3}{4}$-inch bars.

Hence the rate of evaporation is diminished, or, if the air spaces be widened to compensate for the extra thickness of the bars, an attendant loss of fuel is incurred.

By proper management, this inconvenience and loss may in great measure be prevented. For this purpose it is only necessary to adapt the quality of the coke, with respect to its dimensions, to the particular duty it has to perform. Engines running with express or other quick passenger trains, and making few stoppages, require a maximum rate of evaporation which can be attained by feeding only with large round coke, thus allowing the air free access to the interior of the burning mass. The rule formerly practised on the Liverpool and Manchester line was to sort the coke from the waggons into three qualities by the rake. The first quality, or large round coke, was delivered to the passenger engines; the second quality, of an inferior size of round coke, to the luggage engines; and the third, of still less dimensions, to ballast engines. Thus the two latter classes of engines performed their work as efficiently as before, and the passenger engines obtained the benefit of the

* With $\frac{1}{2}$-inch bars and 1-inch spaces, the destruction of fire-bars on the Liverpool and Manchester Railway, on a mileage of 320,000 miles, during the period extending from January 1st to November 10th, 1841, was 5 tons 16 cwt.; Hulton or Worsley coke alone being used.

increase of speed which the first quality of coke afforded by increasing the rate of evaporation. The entire coke purchased was thus made to render effective service; for previously there had been much waste occasioned by the firemen sorting it for themselves on the journey, and throwing out *on to* the road what they considered refuse.

Coke is frequently wasted from want of attention to the fixing of the fire-bars; for unless these are closely wedged or jammed into the frame which supports them, the rapid motion of the engine will cause an incessant friction upon the surface of the fuel at the bottom of the fire, and work a portion of it down into the ash-pan.

The power of fuel to resist mechanical dispersion in the furnace depends on its physical character.

Some kinds of coal contain water in a state of chemical combination, and are apt to split and fly to pieces when heat is applied. The anthracite coals of South Wales are peculiarly subject to this evil. In furnaces of the ordinary construction, and especially in locomotive boilers, it is difficult to use them, as they are apt to break down into powder under the influence of a strong heat suddenly applied. Other kinds, after long exposure to air and weather, appear to undergo a kind of incipient decomposition, which renders them tender and friable. Coke is rendered compact by the process of coking being long continued, producing thereby a sort of fusion between the particles. It is, of course, the manufacturer's interest to employ and replenish his ovens as quickly as possible, and it may therefore happen that the consumers are sometimes sufferers. To withstand the blast of a locomotive furnace, the coking process should be fully completed. Imperfectly coked coal is carried off like chaff through the tubes and up the chimney.

2. *Incomplete combustion of the elements of the fuel.*

Owing to an insufficient supply of air, the volatile products of coal frequently pass off unconsumed, or only partially so. The visible result is the formation of a cloud of smoke from what, before its admixture with air, was an almost invisible gas. This gas, or, at the least, the inflammable part of it, is a compound of carbon and hydrogen united in one or more definite proportions. If oxygen be presented to the gas at a time when its temperature is high enough for the forces of affinity to have full play, but in quantity insufficient to saturate the whole of the carbon and hydrogen, the hydrogen unites with the oxygen before the carbon is taken up, and the carbon is deposited, or rather separated, in the form of smoke.

It would be out of place here to refer to the subject of the prevention of smoke in furnaces, further than to state that a judicious application of the principle of a direct and well-regulated admixture of air with the heated gases, as they are distilled off from the fuel, appears not only to diminish very largely the quantity of smoke evolved from the furnace chimney, but also to effect some saving in fuel. According to Mr. Houldsworth's experiments, reported by Mr. Fairbairn in the 'Report of the British Association' (1844, page 109), an advantage of 12½ per cent. was obtained on the average by the repeated admission of air through apertures behind the bridge. In some cases even a higher duty is said to have been observed.

The reason why the additional heat generated in the full combustion of the gaseous products falls short of the estimates held out by the advocates of different systems of smoke prevention, appears to be that the heat employed in volatilising the gaseous products is nearly as great as the heat evolved in the subsequent combination of those products with oxygen.

A sufficient supply of oxygen is as important in the combustion of solid carbon as it is in that of the volatile parts of the coal; for it is well known that carbon unites

with oxygen in two proportions, forming respectively carbonic oxide and carbonic acid gas.

Carbonic oxide contains . . .	6·12 carbon + 8 oxygen	= 14·12
Carbonic acid contains . . .	6·12 do. + 16 do.	= 22·12

To develope the full heat of which carbon is capable, it must receive the double dose of oxygen, and be converted into carbonic acid.

The fact of the generation and escape of large quantities of carbonic oxide from coke fires, especially where the mass of burning fuel is thick, is abundantly proved by experience. If the fire door of the furnace of a locomotive boiler in full action be opened, a lambent blue flame is at once seen to surround the opening and play over the surface of the fuel, occasioned by the combustion of the carbonic oxide when the fresh air is presented to it. In like manner, a blue flame may occasionally be seen burning at the top of the chimney, the point where, supposing the furnace door to be shut, the heated carbonic oxide first meets a supply of oxygen. If the smoke-box be not quite air-tight, the outer plates have been known to become red-hot by the combustion going on within.

It may be useful to consider what loss of heat may arise as between the conversion of carbon into carbonic acid and of carbon into carbonic oxide. There are no direct means of ascertaining the loss or difference, inasmuch as no direct experiment can be made on the conversion of carbon into carbonic oxide *alone*. We may, however, arrive at a conclusion indirectly in the following way:

According to experiment, cited in the Table (page 486), 1 gramme carbonic oxide, in its conversion into carbonic acid, yields 2431 units of heat.

Consequently, 14·12 grammes of carbonic oxide will yield $(2431 \times 14{\cdot}12) = 34,325$.

But 14·12 grammes carbonic oxide contain 6·12 grammes of carbon.

Therefore the 6·12 grammes of carbon, during the process of conversion from the state of carbonic oxide to that of carbonic acid, yield 34,325 units, equivalent to 1 gramme carbon, in its conversion from carbonic oxide to carbonic acid, yielding 5608 units of heat.

But according to experiment (see page 486), 1 gramme carbon, in its conversion from carbon into carbonic acid, yields 7900.

The difference between the two last numbers indicates the heat developed by 1 gramme carbon, in its conversion from carbon to carbonic oxide, $= 2292$.

If this reasoning be correct, $\frac{5608}{7900}$ths, or, in round numbers, 70 per cent., of the heat which would be generated in the conversion of carbon to carbonic acid, is lost in the case of the conversion of the same weight of carbon into carbonic oxide only.

Every pound of carbon which escapes through the chimney in the form of carbonic oxide carries off, therefore, as much fuel as would suffice to evaporate 10 lbs. of water from the temperature of 212°.

In the locomotive boiler, the remedy has been partially applied of perforating the fire door with a number of small holes, and allowing the air to enter through them direct on to the top of the burning coke, from the surface of which the carbonic oxide is rising.

The various sources of waste hitherto detailed, however insignificant they may appear if considered singly, become, when combined together, of serious moment. This was fully evidenced in the saving of full 100 tons of coke per week, effected in the Liverpool and Manchester engines, in the autumn of 1839, in the following manner.

In the autumn of 1838 an account had been opened, against each engine, of the

coke delivered, and weekly returns were made up of the general consumption. This served, to a certain extent, as a check, but the result was not so satisfactory as could have been desired. The returns might or might not give accurately the week's consumption. The coke was put loose in the tender, subjected to all the breakage to which its position rendered it liable, and being so placed, no account was taken of the stock remaining at the end of the week.

This might have been greater or less than the stock remaining at the end of the previous week. Hence an error in the week's consumption. Taking a longer period, of course the errors were neutralised, and a correct average obtained ; but this was not sufficient. It was necessary to know not merely a month's consumption, nor a week's, but every day's consumption. Nay, it was found important that the drivers should know from hour to hour what they were using. Accordingly the system was changed. The coke, instead of being placed loose in the tenders, was put on in bags, each containing a certain weight, and every night, after the engines had finished work, the remaining ones were counted, and as many fresh ones put on as sufficed to make up a given complement. The driver was not permitted to empty his sacks before he actually wanted to feed his fire, and therefore no waste or breakage could take place. At the same time orders were given to let the fires burn low as the end of the journey was approached, for the purpose of diminishing waste during the intervals of rest.

A table of every week's performance was posted up for the inspection of the men, wherein the engines occupied a higher place in proportion as their consumption was lighter.

These arrangements were carried into effect in October, 1839, and immediately roused an honourable and eager spirit of competition amongst the men.

The records of that period show a marked effect. During the four weeks *preceding* the 19th October, the coke deliveries amounted to 826 tons 9 cwt. ; during the four weeks succeeding that day, to only 717 tons 17 cwt., the work done being almost precisely the same.

Week ending							Tons.	cwt.	qrs.
28 September, 1839.	232	trips of	30 miles	+ $34\frac{1}{2}$	days' work		207	4	2
5 October, ,,	234	do.	do.	+ $34\frac{1}{4}$	do.		203	11	1
12 do. ,,	233	do.	do.	+ $35\frac{1}{4}$	do.		211	2	1
19 do. ,,	236	do.	do.	+ $30\frac{3}{4}$	do.		204	11	0
	935	do.	do.	+ $134\frac{3}{4}$	do.		826	9	0
26 October, 1839.	233	trips of	30 miles	+ 35	days' work		181	8	1
2 November, ,,	233	do.	do.	+ $34\frac{1}{4}$	do.		182	3	1
9 do. ,,	230	do.	do.	+ $34\frac{1}{4}$	do.		174	14	1
16 do. ,,	240	do.	do.	+ $35\frac{1}{2}$	do.		179	11	2
	936	do.	do.	+ 139	do.		717	17	1

By further practice, and by attending closely to those little defects of which the existence was sure to be indicated by an inspection of the tables, and before any extensive improvements were made in the valves, the quantity was still further reduced, and in February of the following year did not exceed 670 tons.

The Working Duty of Steam.

The heat necessary to convert a given weight of water of a given temperature into steam has been ascertained to be a constant quantity, independent of the particular

pressure and temperature of the steam generated, so that in respect of the duty of fuel it is a matter of indifference whether evaporation is carried on under a high or a low pressure.

A portion of the heat applied to the water is expended in elevating its temperature up to the point at which its conversion into steam of the assigned pressure commences, and the remaining portion is devoted to the conversion of the liquid into vapour, and is essential to its constitution as such.

This heat of conversion (latent heat) diminishes as the pressure and corresponding temperature of the steam increase.

For instance :—

	lbs. of water.
1 lb. of water heated from 32° to 212° F. requires as much heat as would elevate through 1° F.	180
1 lb. of water at 212° F. converted into steam at 212° (=14·7 lbs. per square inch) requires as much heat for its conversion as would elevate through 1° F.	972
Total	1152

Again :

1 lb. of water heated from 32° to 329° F. requires as much heat as would elevate through 1° F.	297
1 lb of water at 329° F. converted into steam at 329° (=100 lbs. per square inch) requires as much heat for its conversion as would elevate through 1° F.	855
Total	1152

The number 1152 is, then, a constant which may be taken to express the units of heat containing 1 lb. of steam, reckoning from 32° F., the freezing point of water, up to the temperature at which the conversion into steam takes place.

The *mechanical equivalent*, or maximum theoretical duty of this amount of heat, as contained *in* 1 lb. *of steam*, is

682 lbs. × 1152 units of heat = 785,664 lbs. *raised* 1 *foot high ;*

682 lbs. through 1 foot being, as before shewn, the mechanical equivalent of the unit of heat.

The amount of duty realised in the production and use of 1 lb. of steam falls, however, far short of this theoretical maximum.

In the earliest stages of the process, those which precede the moment when the water finally assumes the gaseous form, the forces to be encountered before the cohesion of the molecules of the liquid can be overcome, absorb and neutralise a large proportion of the effect of the imparted heat.

In fact, the 'heat of conversion' is partly occupied in producing the change of state from liquid to gas, an effect which is unattended by any sensible manifestation of power, and for the remainder consists in producing a pressure of force equal to the tension of the steam on a given area of surface moving through a space which depends on the relative volumes of the water and the steam.

Thus it is obvious that in the most perfect steam engine, acting as it does on the principle of alternate vaporisation and condensation, a very considerable amount of the mechanical equivalent of heat is for all practical purposes annihilated ; and this reflection may lead to the question whether there may not be discovered some means

of reclaiming the lost heat of conversion, and thereby greatly economising fuel, by the employment of water purely in its gaseous form, subjecting it to such alterations of temperature, *short* of reducing it to the liquid state, as may render it the means of transforming all the heat it receives into a manifested and available equivalent of force.

Owing to the circumstance of the heat of conversion becoming relatively less and less as the pressure increases, the loss or absorption of force is less, the higher the pressure at which the steam is produced.

Making the allowance for this loss, the theoretical work producible from 1lb. of steam is in each of the cases here cited as follows:

	lbs. avoird. raised 1 ft. high by 1 lb. of steam. Theoretical duty.
1st. Low-pressure engine, working inexpansively, and condensing its steam at 112° F. (= 1·3lb. per square inch); the steam formed at 228° F. (=20lbs. per square inch)	53,150
2nd. High-pressure engine, working expansively; steam formed and admitted into cylinder at 284° F. (=51½lbs. per square inch, or 3 atmospheres), expanding to 104° F. and condensed at 104° F. (=1 lb. per square inch)	214,734

In the first case only $\frac{1}{14}$th part of the absolute maximum of theoretical duty of the heat imparted to the steam can be obtained; in the latter case, about $\frac{4}{7}$ths.

Of this reduced theoretical duty let us see how much has been actually obtained in practice.

1*st case.*—Mr. Josiah Parkes, in his Paper on Steam Engines, records the duty of two condensing inexpansive low-pressure steam engines, viz., an engine at Warwick, with 25-inch cylinder and 5-feet 6-inch stroke, and the engine of the Albion Mills, London, with 34-inch cylinder and 8-feet stroke.

The first engine raised	28,285 lbs. 1 foot high.
The second engine raised	28,489 lbs. ,,
Mean	28,387 lbs. raised 1 foot high by 1 lb. of steam.

This duty is only 53 per cent., or little more than one-half the assigned theoretical duty.

2*nd case.*—The Fowey Consols engine, with 80-inch cylinder, 10-feet 4-inch stroke, cutting off at ¼ stroke, working at a pressure of 40 lbs. per square inch above the atmosphere, has raised

126,359 lbs. 1 foot high by 1 lb. of steam.*

This duty amounts to at least 58 per cent. of the assigned theoretical duty. (In the case supposed, the steam would be cut off rather earlier.)

The loss of duty in respect of the steam generated in the boiler may be referred to four general heads, viz.

I. Loss as arising from steam which escapes, either without passing through the cylinders, or, if passed through the cylinder, without exerting pressure upon the piston.

II. Loss as arising from resistances against the piston, produced by imperfect action of the valves.

* The average duty of all the Cornish engines scarcely exceeds one-half this.

III. An *apparent* loss incidental to the non-condensing engine, as arising from the resistance to the piston afforded by the pressure of the atmosphere.

IV. Loss as arising from imperfect condensation.

Four trips, 30 miles each, made by each of the following Engines.	Average loads.	HOURS OF WORK.			CONSUMPTION OF COKE.								Consumption per hour when at rest.
		In motion.	At rest.	Total.	Whilst in motion.		During the day, actually burnt or lost.		During the day, waste excepted.		During the whole day's work, waste included.		
					Per trip.	Per mile.*	Per trip.	Per mile.	Per trip.	Per mile.	Per trip.	Per mile.	
		h. m.	h. m.	h. m.	c. q. lb.	lbs.	c. q. lb.	lbs.	c. q. lb.	lbs.	c. q. lb.	lbs.	lbs.
Rapid........	10 carriages	6 21	11 19	17 40	9 0 3	33·7	10 1 20	38·9	10 2 24	40·0	10 3 0	40·1	67
Leopard	8 ditto	5 56	10 52	16 48	8 2 25	32·6	10 2 17	39·3	10 3 19	40·8	11 1 0	42·0	97
Lion	15 waggons	7 22	9 13	16 35	10 2 3	39·4	11 3 10	44·2	12 0 25	45·6	12 1 8	46·0	99
Mammoth ...	17 ditto	7 0	12 55	19 55	12 0 25	45·6	13 2 2	50·5	14 0 10	52·9	14 0 14	52·7	63

I. *Loss from Escapes of Steam.*

Owing to defects of mechanical construction, or to the gradual wear and abrasion of surfaces intended to work upon each other steam tight, a waste of steam often takes place. This can only be remedied by repairs; but there is another fertile source of waste, which is in great measure under the immediate control of the engine-driver,—the loss of steam blown off through the safety valves when the engine is either standing or working. To give an idea of the loss that may be sustained in this way, the following experiments, made on the Liverpool and Manchester Railway in August, 1839, may be cited.

Four engines in good working order, viz. the 'Rapid' and 'Leopard' passenger engines, and the 'Lion' and 'Mammoth' luggage engines, were selected; and during a day's work of each, as engaged in the ordinary traffic of the line, all particulars of their service were noted down: the time in motion,—the time at rest under steam,—the times of lighting and extinguishing the fires,—the coke delivered throughout the day,—the waste coke thrown aside as useless,—the ashes taken out at night.

The results of these experiments are condensed into the annexed Table, the consumption of fuel being reduced to a mileage rate.

By this account it is seen, that under circumstances in which more than ordinary care was taken in the working of the engines, the waste of coke going on whilst the engines were at rest averaged about 80 lbs. per hour; or, calculated upon the mileage, about 7 lbs. per mile, being an increase of more than one-sixth on the net consumption whilst in motion.

The trial led to a few simple regulations, which resulted in effecting the saving of nearly the entire quantity of fuel consumed whilst the engines were standing. These were as follows; as the engine approached the end of its journey, the fire in the fire-box and the water in the boiler were allowed to run low. Before reaching the station, the feed-pumps were put on and the boiler filled up with water from the tender, the water being of course comparatively cold; after the fire-man had cleaned his bars and picked the tubes, the fire-place was filled up with cold coke: a damper was placed over the mouth of the chimney, and the engine remained in this condition until the time of starting on its next journey. By this time the coke had become ignited throughout; the water had been raised to the boiling point, and if any steam had been generated, it was turned into the tender tank, to warm the feed water. Thus the heat produced during the interval of rest was turned to full account, and made to tell directly upon the work of the succeeding journey.

II. *Loss from Resistances against the Piston, produced by imperfect Action of the Valves.*

This is a branch of the subject deserving especial consideration. Its importance, as referring to the economical working of steam engines, may be profitably illustrated by a brief historical account of the consecutive alterations and improvements in the valve arrangements and mechanism of the locomotive engines of the Liverpool and Manchester Railway, and of the results produced in the saving of fuel.

It may be premised that the same principles have their application not only to the engines of other railways, making due allowances for difference in the gradients and difference in the loads and dimensions of engines, and difference of speed, but also to fixed engines in general. In fact, they have been applied to the fixed engines of the Liverpool and Manchester Railway with parallel advantageous results.

The history of the Liverpool and Manchester locomotive engines may, in reference to economy in working them, (for the sake of convenient classification) be divided into two periods; the first a period of increasing, the second a period of decreasing consumption, as respects the article of fuel. Brief allusion may be made to the events of both periods, and a reference to the causes which retarded, as well as to those which accelerated, improvement.

During the first few years after the opening of the railway, the class of improvements comprising the gradual enlargement of dimensions as necessary for maintaining higher rates of speed, and the transport of heavy loads,—the better disposition and proportionment of the component parts, and selection of suitable materials capable of resisting heavy strains, and various other causes of derangement and decay, demanded, in consequence of their direct influence upon the traffic of the Company, unremitting attention. The necessity of securing regularity in the transport of trains, whether of passengers or goods, was pressing and paramount, and afforded sufficient materials for thought and experiment. It is, therefore, a source of less surprise than regret that little progress should have been made in diminishing the consumption of fuel. Trials of the consumption of different engines of similar size and power were made from time to time; and these agreeing pretty closely together, served to lull suspicion of unnecessary waste of fuel. As the engines increased in dimensions, the consumption of fuel increased also, which was considered a natural and inevitable consequence of the exertion of increased power.

The adoption, in 1836, for the passenger traffic, of what were termed short-stroked engines, was attended with the establishment of a quicker rate of travelling than had before been known on the line, but, unfortunately, also with an extravagant increase in consumption of coke. This was erroneously referred to the mechanical disadvantage

of the short stroke, an explanation which for a time was deemed satisfactory. Attention was directed to schemes of smoke-burning, by which the use of coal, as a much cheaper fuel than coke, might be rendered possible. In 1836 the 'Liver' was fitted up for burning coal, but proved a failure; and subsequently one or two engines were tried with about equal success. Hitherto all the engines had been furnished with the slide valve ordinarily used in high-pressure engines, the mode of operation of which is well known to every practical mechanic. It will be remembered, that the operations of admitting the fresh steam and releasing the waste steam are alternately performed by the same valve and by the same motion. The valve being made to slide backwards and forwards upon the face of the ports, opens and closes the several passages in their turn. The two extreme ones, termed steam ports, communicate with either end of the cylinder. The middle one is termed the exhausting port, and its corresponding passage terminates in a pipe open to the atmosphere and carried into the chimney. Steam is admitted freely into the steam chest from the boiler. The valve is made of sufficient length to cover, when placed in the centre of the stroke, *all* the ports. In this position no steam can enter the cylinder; but as the valve moves on, one of the ports opens, and the arrangement of the valve gearing is such, that when the piston is ready to begin its stroke, the steam port *begins* to open. During the forward progress of the piston, the valve not only travels to the end of the stroke, but returns to the point from whence it set out. Its continued motion in the same direction finally closes the valve, and prevents any further admission of steam. The steam has now done its work, and must be removed. In the middle of the valve a hollow chamber is formed, of sufficient length to span between the ports. As soon as the edge of this chamber passes the edge of the steam port, the pent-up steam finds vent, and, rushing through the chamber into the exhausting passage, escapes into the chimney.

This was the valve used on the Liverpool and Manchester Railway until the year 1838, and also in the engines of other lines of railway at that time. It will be observed that the exhausting port opens when the steam-port closes, and both events happen as nearly as may be at the end of the stroke. The perfection of a slide-valve consists, other things being supposed equal, in the degree of nicety with which its motion is timed, relatively to the motion of the piston. The functions of the piston are absolutely dependent upon the proper timing of the admission and release of the steam. A most slight and apparently trifling error in the adjustment produces a most serious effect upon the consumption of fuel.

If from any cause the valve should open to admit steam for a fresh stroke before the preceding stroke is finished, it opens too soon, and an unnecessary resistance to the piston is produced.

If, on the other hand, the valve should delay its opening until the piston has begun to return, it opens too late, because then the steam has uselessly to fill the space left vacant. Hence a waste of steam and loss of power. As far, then, as the admission of steam is concerned, it is a necessary condition that the steam-ports should open neither before nor after, but at the precise moment when the stroke commences. Some engineers, indeed, have recommended giving the valve 'lead,' as it is termed, —that is to say, setting it so as to open a little before the completion of the foregoing stroke; but it seems very questionable whether advantage is gained by doing so, excepting to the extent that may be necessary to compensate for any slackness in the parts of the valve gearing, or for their expansion when hot, and about one-sixteenth of an inch may be considered sufficient for this purpose in a well-constructed engine.

This valve satisfies the conditions required in the admission of steam. It opens exactly at the right time. The steam begins to enter as the piston begins to move,

and follows it steadily and effectively throughout its course. Whatever time the piston takes for its journey, the steam is allowed as much time to follow it. At first the opening is small, but then the motion of the piston is comparatively slow, and therefore the supply keeps pace with the demand. As respects the release of the steam when the stroke has been completed, the performance of this valve is altogether unsatisfactory; and here lurks the cause of the difference in the performances of the old and the later engines of the Company.

But it might be said, the release does appear to take place at the right time, because it occurs just when the piston has finished the stroke, and if it were to occur before, a loss of power would ensue. This is a plausible view of the case, and one which undoubtedly delayed for years the saving of fuel which has since been effected. Sufficient attention was not bestowed upon the processes going on in the interior of the cylinder, or upon the facts which might have indicated them. Alternately to fill and empty the cylinder of its contents are operations requiring time. The time allowed for the first operation,—that of filling the cylinder with steam,—necessarily corresponds with the duration of the stroke, whatever its duration may be. But this cannot be the case as regards the second operation—the emptying of the cylinder. This ought to be performed in an instant, in the minutest fraction of the duration of the stroke, otherwise the steam continues pent up when it ought to be liberated, when it ought to assume its minimum pressure,—viz., the pressure of the atmosphere,—and exerts an injurious counter-pressure against the piston, tending to increase the resistance to be overcome. To effect the free and rapid discharge, it is necessary not merely to open the communication to the exhausting pipe, but to open a wide passage, and to have this *done* by the time the piston recommences its motion. The valve alluded to cannot accomplish this. Its motion is gradual, not instantaneous. The passage only begins to open when the piston is on the turn, and is not wide open until the piston has travelled through one-tenth of its entire stroke. The steam in the cylinder is consequently restrained from escaping, being wire-drawn in the passage out, and consequently takes considerable time to assume the pressure of the atmosphere. In the meanwhile the new stroke has begun, and been partially completed; and so far the piston has had to contend with a resistance altogether illegitimate—a resistance which in many cases, and especially at high speeds, has been nearly equal to all the other resistances put together. In the year 1838, as above mentioned, the extent of the disease was first suspected, and a remedy attempted. It had before been observed that the giving of an engine 'lead' tended to improve its speed when travelling, already at a high speed, and with a light load. The circumstance was attributed to the opening of the steam-port being wide at the time of commencing the stroke, thereby increasing the facility for the entrance of the steam in following up the piston. Its true explanation was found to be the earlier release of the waste steam, and consequent diminution of resistance. As sometimes three-eighths of an inch, or even half an inch, 'lead' was given in passenger engines, it was decided to try the effect of opening the exhausting passage earlier by the same amount, whilst the steam-port should still be made to open only at the turn of the stroke. An engine called the 'Lightning' was chosen for the experiment. By placing the valve on the ports, so as to allow the exhausting passage to be three-eighths of an inch open, the steam-port would be at the same time a quarter of an inch open. This space, therefore, was closed by adding to the length of the valve at each end a quarter of an inch. The eccentric was of course shifted on the axle to correspond with the alteration, and the engine with the altered valve was again set to work, in March, 1838. The amount by which the valve at each end overlaps the steam-ports, when placed exactly over them, is technically termed the 'lap.' The lap of the 'Lightning's' valve

being, then, three-eighths of an inch, the exhausting passage was about three-eighths of an inch open when the stroke was finished. This engine was made the subject of several experiments. With coach trains, the saving in fuel was very considerable; the consumption, whilst running, being only about 25 lbs. per mile with loads of 5 to 8 coaches, and the speed was considerably improved.

It here becomes necessary to refer to the consumption of the Liverpool and Manchester engines before and at the time we speak of, in order to form a just conception of the position arrived at. The amended performance of the 'Lightning' was little better than the best performances at the end of the year 1830. The 'North Star,' 'Phœnix,' 'Arrow,' and 'Meteor,' engines of that period, when in first-rate condition, and expressly put upon trial, consumed about 25 lbs. per mile; but this was with loads of only 4 carriages, and at a very inferior speed.

Again, in June, 1832, the 'Victory' and 'Planet' were burning about 30 lbs. per mile, with coach trains. In 1833 the 'Sun' and 'Etna' used about 28 lbs. per mile. This is their consumption when actually running—*i.e.*, their net consumption.

The experiments of M. de Pambour, in 1834, were carefully conducted, and may be fully relied upon. In his 'Treatise on Locomotive Engines' (2nd edition, page 312, 1840), he gives a table, by which it appears that the best performances of the best engines, as the 'Jupiter,' was 26·3 lbs. of coke per mile, with 8 coaches, at 24·58 miles per hour; and the best performance of luggage engines, 38 lbs., with 25 waggons (=120 tons), at 17 miles per hour. This was their net consumption. The distinction between the total amount of fuel consumed by any engine, and the fuel it consumes when actually running, must be carefully borne in mind. It will be marked by the terms *net* and *gross* consumption. Coke must be burnt in raising the steam, and afterwards in keeping it up during the intervals of rest, which, therefore, enters into the gross but not into the net consumption. In 1836 and 1837 larger engines were gradually introduced to replace the smaller class, which had become insufficient for maintaining the higher rate of speed then demanded; and their increased consumption of fuel was commensurate with their increase of size.

For an idea of the general effect attendant upon their introduction, the following table, showing the coke consumed in several consecutive years, may be consulted :—

11,561	trips in	1835	=	7,907	tons coke gross.
12,063	,,	1836	=	9,876	,,
12,953	,,	1837	=	10,816	,,

Thus, during three years, when the change went on, although the work done increased only in the proportion of 100 to 112, the consumption of fuel increased in the proportion of 100 to 136, without any material difference in the magnitude of the loads.

In 1838 and 1839 the average consumption attained its maximum, being about 49 lbs. per mile gross, with passenger trains averaging 7 coaches, and 54 lbs. per mile with luggage trains averaging 16 waggons.

Forty lbs. net consumption with coach trains was moderate for such an engine as the 'Lightning'; and the performance of the 'Lightning' when altered, being under 30 lbs. net, was naturally considered favourable. This result was evidently obtained from the earlier exhaustion of the steam; whereas, previously, the opening of the exhaustion passage was contemporaneous with the termination of the stroke, now it took place before, and was already three-eighths of an inch open at the end of the stroke. A portion of the steam could by that time escape, and the back pressure was diminished. The valves of two engines called the 'Rapid' and 'Arrow' were

next altered to have three-eighths of an inch lap—the 'Rapid' in January, the 'Arrow' in June, 1839. During the last quarter of the year 1839, the gross consumption of the 'Rapid' was 36½ lbs. per mile, and that of the 'Arrow' 40 lbs. per mile, and the net consumption probably about 30 and 33 lbs.

'Arrow' valve with three-eighths of an inch lap.

Week ending—		cwt.	qrs.	lbs.
January 4, 1840—12 trips of 30 miles	.	130	0	0
,, 11, ,, —12 ,, ,,	.	127	2	0
24		257	2	0

	cwt.	qrs.	lbs.	lbs.
Consumption per trip	10	2	25	
,, ,, mile				40·1

Valve with three-fourths of an inch lap.

Week ending—		cwt.	qrs.	lbs.
February 9, 1840—10 trips of 30 miles	.	88	3	0
March 7, ,, — 8 ,, ,,	.	71	1	0
,, 21, ,, —14 ,, ,,	.	118	3	0
,, 28, ,, —16 ,, ,,	.	137	2	0
48		416	1	0

	cwt.	qrs.	lbs.	
Consumption per trip	8	2	19	
,, ,, mile				32·4
Difference				7·7

Here was a confirmation of the principle first recognised in the case of the 'Lightning;' and it became a question how far this principle might be advantageously carried out, and whether the exhaustion might not be made to take place still earlier. This could not be accomplished without at the same time cutting off the steam earlier; or, in other words, by virtually shortening the stroke. The fear of impairing the power of the engine at first deterred from venturing the experiment; but at length a trial was made in the 'Arrow,' whose valve was altered to have ¾ths of an inch instead of ⅜ths of an inch lap at each end. Since the travel of the valve remained as before, the valves did not open quite full port, but only ⅞ths of an inch. In February, 1840, the alteration was effected, and an immediate reduction of nearly 8 lbs. per mile was the result. The gross consumption of this engine, with coach trains, was 40·1 lbs. before the alteration; it was only 32·4 lbs. after it. A saving of 20 per cent. had been effected: but, at the same time, no injurious effect was observed upon the power, but rather the reverse.

An invention, which was made a little before the time we now speak of, tended more completely than anything had hitherto done to shew the impossibility of fixing any ultimate determinate standard of consumption, and consequently gave a considerable impulse to the further improvement of the engines. This was the patent expansive valve gearing of Mr. John Gray, as applied to the 'Cyclops,' an engine of the same dimensions and make as the 'Lightning.'

This engine underwent a thorough repair in the summer of 1839; and in October, soon after it came out, was made the subject of an extensive series of experiments.

The alteration consisted in the adaptation of particular mechanism for working the valves, whereby the engine-man was enabled, without disturbing the regulator, to vary at pleasure the quantity of steam admitted into the cylinder within the limits of a range

extending from 46 to 82 per cent. of the length of the stroke, allowing the steam to act expansively after being cut off.

The advantages proposed to be attained by the arrangement were, to accommodate the power of the engine to the load to be conveyed, and to the inclinations of the road; to establish, in fact, a property of adjustment, by the aid of which an engine, constructed for the transport of very heavy loads, might be adapted to the exigencies of an irregular and uncertain traffic, without entailing any unnecessary expenditure of fuel.

The conclusion arrived at upon completing the experiments was, that a saving of at least 12 per cent. in fuel over the best engines had been effected by the application of the new gearing, without occasioning any diminution in the speed of travelling.

Its net consumption was $22\frac{1}{2}$ lbs. per mile; its gross consumption $28\frac{1}{2}$ lbs. per mile with loads of seven coaches.

This, though little better than the performance of the 'Arrow,' in March, 1840, was, it will be remembered, accomplished four or five months before, and was, in fact, the cause of a keener prosecution of the trials with different valves.

Whether or not the favourable results of the 'Cyclops' were actually due to using steam expansively, is a point upon which engineers may not perhaps be agreed; but the subsequent history of the locomotive engine has made it apparent that the expansive action only partially contributed to the success of the experiment.

In Mr. Gray's apparatus the time of closing the steam port was made to vary by altering the length of the travel of the valve, and a simultaneous adjustment of the position of the valve on the ports took place to suit the altered travel, making the valve still to open at the right time. The old valve would not have been applicable, nor have fulfilled the specified conditions; for, bearing in mind that in any case the steam port is to open when the stroke of the piston commences, and that the old valve was scarcely longer than was just sufficient to cover both steam ports, it is evident that an alteration merely in the travel of the valve would not have allowed the steam to act expansively, since the steam can only so act when both steam ports are closed; that is, whilst the valve is travelling through a space equal to the length of the external lap, plus that of the internal ($=\frac{7}{8}$ inch $+\frac{3}{8}$ inch $=1\frac{1}{4}$ inch in the case of the 'Cyclops'). Therefore lap was given to the valve both internally and externally; internally, to delay the opening of the exhausting passage; externally, that time might intervene between the operations of exhausting the waste and admitting the fresh steam.

And inasmuch as the external lap exceeded the internal, by so much the arrangements resembled, and in fact partook of the principle of the valve of the 'Rapid' and 'Arrow,' the result of their difference being, that the exhausting passage was half an inch open at the end of the stroke.

To this principle, viz., the earlier exhaustion of the waste steam, and to the higher pressure of steam in the boiler, may be ascribed the improvement in the 'Cyclops.' Whatever benefit may have been derived from expansive working was, to a considerable extent, neutralised by the compression of the waste steam left in the cylinder after the closing of the exhaustion passage, an evil which increased in proportion as the steam was cut off earlier.

The next important improvement in the valves is due to Mr. Dewrance, and was suggested by him early in the year 1840. His principle was, that the exhausting passage, instead of being only partially open at the moment of completing the stroke, as was more or less the case with the engines before named, should be nearly wide open, which was to be accomplished by making the 'lap' of the valve equal to the width of the steam port. Moreover, that the travel of the valve should be made pro-

portionate to the increased lap, so as to allow the same area or the same amount of opening of the steam port for the admission of steam. This latter condition was not fully obtained in the instances of the 'Lightning,' 'Arrow,' and 'Rapid.' It would at least have involved the sacrifice either of the eccentrics or other parts of the valve-gearing, in order to obtain the additional travel of the valve, and perhaps might have been altogether impossible from want of room in the steam-chest itself. Therefore, in those engines, after being altered, the valves did not open so wide as before.

A favourable opportunity now occurred for carrying out these ideas, both as regarded increased lap and increased travel, from the circumstance of two engines requiring extensive repairs, which would allow time for the needful alterations.

One inch lap was given to the 'Rapid's' valve, which was now made to travel 4½ inches. The result of this arrangement was, that the exhausting passage was one inch open at the end of the stroke, and that supposing the stroke of the piston divided into 100 equal parts, the steam was cut off at 79, it expanded from 79 to 95; at 95 it began to be released, and was escaping into the atmosphere from 95 to 100.

The 'Rapid's' gross average consumption of coke, when running sixty-four trips of thirty miles each with coach trains, before the alteration, was 36·3 lbs. per mile; and 28·6 lbs. per mile immediately after the alteration. Thus we have a measure of the effect produced—a saving of one-fourth of the fuel.

It had become a question whether the Company shall not proceed to adapt the expansive-gearing to more of their engines; but an engine having now been made to rival the 'Cyclops,' without in any degree increasing the complexity of the gearing, it was considered more desirable to delay proceedings until the simpler method was fully tested by numerous experiments.

To accomplish this in the then existing engines was found to be no easy task; for on examination it was discovered that, in many cases, there was no room in the steam-chest for valves of greater lap; in others, that it was impossible to increase the length of travel. Therefore, it was necessary to prepare, in the first instance, for the sacrifice of at least the cylinders, steam-chests, working-gear, and inside framing of several engines then needing repair, and eventually, as resources would permit, for replacing the Company's entire stock with new engines, all built according to one model, combining the latest improvements experience had shown worthy of introduction, trusting that the saving in fuel, and in the general expenses of repairs, would speedily repay the Company for the immediate sacrifice. These views fortunately proved to be well founded. The loss was soon recovered; for the saving in the cost of fuel and repairs considerably exceeded the outlay, and although during the years 1840, 1841, 1842, the Company turned out from their workshops twenty-four new engines (the cost of the whole being debited to current disbursements, under the head of 'Locomotive power'), and broke up as many old ones, yet at the same time, the total expenses of the locomotive department underwent a gradual reduction from 51,580*l.* per annum, the charge in 1839, to 25,732*l.*, the charge in 1842.

Some engines, such as the 'Vesta,' 'Swiftsure,' 'Phœnix,' 'Etna,' 'Rokeby,' 'Meteor,' and 'Sun,' were altered at a trifling expense, so as to approximate towards the improved principle, and thus tended to keep down the consumption of coke whilst more perfect engines were in course of formation.

The 'York' was several months under repair, and did not come into action until 1841.

Finally, all the engines belonging to the Company were furnished with the improved valve, answering to the 'Rapids,' the lap being 1 inch, the travel 4 inches,

the ports $1\frac{1}{8}$ inch wide. In casting new cylinders, great care was of course taken to enlarge the area of the passages of exhaustion, most of the older engines having been too much contracted at this part. Attention to this point exercised a further beneficial effect in saving fuel.

Every step towards increasing the 'lap' was found to conduce to the good working of the engine. The waste steam was no longer choked up in the cylinder; its prejudicial resistance was removed, and, in consequence, a much less quantity of steam and fuel sufficed to do the same useful work. As a further consequence, the area of the blast pipe could be enlarged without risk of a deficiency of steam, the coke was no longer chafed by the violence of the draft, and the fire-bars could be placed closer together, to diminish the loss of fuel dropping between them.

Having considered the effects of the old and the new valve with reference to the motion of the piston, it may be interesting also to compare the times allowed in either case for the performance of the function of releasing the steam, as by so doing we may gain a clearer conception of the difference subsisting between them.

Supposing the velocity of the engine to be uniform, the angular velocity of the crank is uniform also. Half a revolution of the crank, equal to 180°, corresponds with one stroke of the piston. Let us assume the stroke, or, which is the same thing, a half revolution of the crank, to be accomplished in a unit of time.

We shall find as a matter of fact, from the known relative motion of the crank and piston rod, that the angular motion of the crank from the initial or dead point has been as follows, up to the moment when the exhaustion passage begins to open, the valve being set without lead.

	Angular motion of crank from dead point.	Remaining to be passed over.
Valve with 0 inch lap	0° to 180°	0°
,, $\frac{3}{8}$,,	0° to 165°	15°
,, $\frac{3}{4}$,,	0° to 158°	22°
,, 1 ,,	0° to 153°	27°

Therefore the times are as

$\frac{0}{180}$ corresponding with	Old valve,
$\frac{15}{180}$,,	Lightning's,
$\frac{22}{180}$,,	Arrow's,
$\frac{27}{180}$,,	New valve,

or as the numbers 0, 15, 22, 27 which represent the relative times allowed for performing the release of the steam by the four different valves.

There is of course a limit to the application of this principle. The time gained for exhaustion is time lost, as regards the application of the power of the steam : in other words, the sooner we begin to exhaust, the sooner we must cut off the steam, the more we must reduce the length of the effective stroke.

Finally, a point is arrived at where the loss of power from earlier cutting off is equalled by the illegitimate resistance of back pressure removed, and up to this point we cannot do wrong in going; for then, without impairing the useful power of the engine, we are saving all the fuel necessary to overcome what would otherwise be back pressure. In practice it is found, that under an equal pressure of steam the one inch lap does not impair, but rather improves the tractive power of an engine when travelling with a maximum load, and not more, therefore, with any load short of the maximum.

III. *Loss from Resistance of Atmosphere against the Piston.*

This is a loss incidental to all forms of the non-condensing engine ; but its amount

varies relatively to the useful effect produced, according to circumstances over which the engineer has in some measure a control, and it rests with him so to proportion the dimensions of the cylinder, and the speed of the piston to the resistance required to be overcome, as to render the loss the least possible.

After the exhausting passage has been fully opened, and before the piston begins its stroke anew, the cylinder, being now open to the atmosphere, is filled with steam equal, at least, to the pressure of the atmosphere; which pressure therefore has now to be driven before the piston. The quantity of steam expended in neutralising the pressure of the atmosphere for one stroke of the piston is a volume equal to the contents of the cylinder at a density corresponding with the pressure of 14·7 lbs. per square inch, and the volume of water necessary for producing it is equal to $\frac{1}{1700}$th part of the volume of such steam.

The evaporating power of any given boiler being limited, it is easy to see that the area of the piston and the velocity of its motion must bear a direct reference to the rate of evaporation; for otherwise a result ranging between the two following extreme cases may occur: either the volume measured out by the pistons in a given time may be smaller than the boiler is competent to fill with steam of the requisite density,—in which case the pressure in the boiler will increase, and the excess of steam will escape through the safety valves,—or the volume measured out by the pistons in a given time may be so great as to reduce the pressure until it scarcely exceeds that of the atmosphere; in which case the force of the steam generated is nearly wholly absorbed in overcoming the atmospheric pressure on the pistons.

In fixed engines, working as they generally do under nearly constant loads at nearly uniform velocities, the relation between useful effect obtained and the work expended in neutralising the pressure of the atmosphere, seldom varies, at least not sufficiently so to attract attention; but in locomotive engines the tendencies towards the above-mentioned extremes are more strongly marked, in consequence of the great variation in load and speed to which they are constantly subject.

In any non-condensing engine we may conceive the duty of the water evaporated, and therefore of the fuel which produces the evaporation, taken irrespective of waste, as divided into two parts, one of which is constant for equal spaces traversed by the piston or by the engine, the other variable and dependent upon the load.

If we take as an example the Liverpool and Manchester passenger engine of 1840 to 1845, with 12-inch cylinders, 18-inch stroke, and 5-feet wheels, and take one mile as the unit of distance traversed, we find the volume of steam expelled to be

336 revolutions × 4 cylinders full × 1·162 cube feet = 1562 cube feet per mile.

With the ordinary loads of say seven or eight coaches, about 15 lbs. of coke are consumed, and (15 × $7\frac{1}{2}$) 112 lbs. of water. 112 lbs. of water converted into 1562 cube feet of steam has its volume increased 869 times, which answers to a pressure of 30·5 lbs. per square inch as the average total force applied to the piston. Of this total force 14·7 lbs. are expended in neutralising atmospheric pressure, and the remainder only to overcoming the external resistances of the engine and train. Here loss from pressure of the atmosphere is as great as the useful effect.

Apply the same engine to the conveyance of a heavier load, say a luggage train of 100 tons: the consumption of water now becomes 150 lbs. per mile instead of 112 lbs. as before, with the lighter load; but the steam used in overcoming atmospheric pressure is the same.

The relation between the total work of the steam and the useful effect has therefore changed from the ratio of

100 : 50 in the 1st case, to that of
100 : 62 in the 2nd case.

Suppose the area of the cylinders of the same engine reduced to *half* their original size, all other parts remaining the same, but the working pressure increased to make up for the reduction of area; then the loads being as before, the relation of total work to useful work will be as the ratios

100 : to 74 in the 1st case,
100 : 80 in the 2nd case,

which is equivalent to a gain of about 20 per cent.; or if we suppose the area of the cylinders to be *doubled*, the ratios would become as

100 : 0 in the 1st case,

indicating that no useful effect is obtained, and that the whole of the steam is applied to the neutralising atmospheric pressure, and as

100 : 24 in the 2nd case.

The practical considerations which limit and determine the proper proportions of the cylinder and wheels are chiefly these:—1st, The most convenient maximum working pressure, having due regard to safety; 2nd, The maximum resistance to be encountered by the engine, say at starting or at any stage of its journey; 3rd, The surplus power in excess of maximum resistance, as necessary for obtaining a sufficiently rapid acceleration of speed after starting a train.

The evaporating power of the boiler must necessarily be a function of the speed to be maintained under the conditions of the average resistance.

In engines of different proportions, the "constant" consumption of water and fuel will vary directly as the square of the diameter of the cylinder, directly as the length of stroke, and inversely as the diameter of the driving wheels: in other words, it will be proportional to the volumes of steam measured off by the cylinders in traversing the same unit of distance.

Computing the "constant" consumption for three sizes of engine, viz.,

No. 1. The Liverpool and Manchester passenger engine, above referred to, ...	12″ cylinder, 18″ stroke, 5-ft. wheels,
No. 2. The larger and standard size now made for trains running between Liverpool, Birmingham, and Manchester, . .	15″ cylinder, 20″ stroke, 6-ft. wheels,
No. 3. The Great Western Railway passenger engine, 'Great Britain,'	18″ cylinder, 24″ stroke, 8-ft. wheels,

we have

No. 1,	consuming	57·26 lbs.	of water per mile,	and	7·63 lbs.	of coke per mile,
No. 2,	,,	82·83	,,	,,	11·04	,,
No. 3,	,,	107·36	,,	,,	14·31	,,

(allowing $7\frac{1}{2}$ lbs.* water to 1 lb. coke), before any effective work can be obtained from the steam.

It would be impossible to prescribe any general solution of the problem of the proportions of the cylinders and driving wheels of engines, seeing that very various and complicated considerations are involved, referring to conditions imposed by the

* *i. e.* $7\frac{1}{2}$ lbs. of water evaporated from say 50° F.

nature and amount of the traffic; as, for example, the extent to which it must be subdivided into individual trains,—the speed at which it has to be conveyed,—the gradients of the railway. Nevertheless, it may be borne in mind that the greater the pressure at which the steam is made to act in the cylinders, and the smaller the volume of steam emitted on the journey, the greater will be the saving in fuel.

Generally speaking, the pressure of steam in the cylinder is much below the pressure in the boiler when the engine is travelling at a high speed.

On starting a train, or for enabling it to surmount an occasional steep inclination, it is most desirable to have large cylinders, to gain the requisite amount of power; but when the speed has been attained, or the incline surmounted, the force is reduced, the steam becomes attenuated in the cylinders, and the large cylinders are the direct occasion of waste of fuel, and in fact prevent the attainment of as high a velocity as would result under the same circumstances, were the cylinders smaller.

The contrivance of some easy method of varying the power of an engine whilst in motion is still a desideratum.

In one way, indeed, this is already in many instances done by cutting off the steam at different points of the stroke, and working expansively; but considering the comparatively low average pressure which the steam assumes in the cylinder at high speeds, and that it cannot be allowed to expand *below* the pressure of the atmosphere,—also that the last atmosphere remaining in the cylinder has not taken any part in the "effective" duty of the engine, but is, so to speak, thrown away, whether the engine is worked expansively or not,—it seems very doubtful in theory, and the results of practice would seem to confirm this view, whether any real advantage is gained by the so-called expansive working.

Some simple and inexpensive means of effecting a condensation of the *last* remaining atmosphere of steam, reserving the excess above one atmosphere for producing the blast, combined with the means of working expansively, would effect all that is desired, and at the same time permit a reduction in the size and weight of the boiler and engine.

IV. *Loss as arising from imperfect Condensation, and from heat carried off by, and not recovered from, the condensing Water.*

In the condensing engine, the heat abstracted from the steam is imparted to the injection-water, and to the water surrounding the condenser, and the temperature of the condensing water is elevated. The resistance to the piston, per unit of surface, after condensation has taken place, is equal to the tension of saturated steam, as answering to the final temperature of the injection-water.

At a temperature	60° F.	the force of vapour is		0·26 lb.	per square inch.
,,	80° F.	,,	,,	0·50 lb.	,,
,,	100° F.	,,	,,	0·93 lb.	,,
,,	120° F.	,,	,,	1·65 lb.	,,
,,	140° F.	,,	,,	2·88 lb.	,,

In condensing a given weight of steam, the greater the quantity and the lower the temperature of the injection-water used, the less will be the tension of vapour, and consequent counter-pressure.

In practice, a final temperature of 120° F. in the injection-water = 1·65 lb. pressure per square inch, may be considered an average result. Suppose the initial temperature

to be 52°, the quantity of injection-water admitted must be at least 16 times the weight of steam condensed; for

	Units of heat.
In 1 ℔. of steam there exists, as measured above the freezing point (32° F.)	1152
From this deduct 120° − 32	88
The difference in the number of units of heat abstracted from the steam to reduce it to water and vapour at the final temperature of 120° F. = ...	1064

To every pound of the cold injection-water (120°—52° =) 68 units of heat are added; consequently $1064 \div 68 = 15 \cdot 6$ ℔s., the weight of water required to condense 1 ℔. of steam, about $\frac{1}{16}$th part of the heat imparted to the injection-water, when pumped out of the condenser, is restored to the service of the engine: the remaining $\frac{15}{16}$ths go to waste.

It has been ingeniously proposed in a recent patent, that of Mr. Siemens, to obviate much of this loss by employing a peculiar form of condenser and arrangement of the valves, by which the steam issuing from the cylinder shall be presented in successive portions to a range of compartments in the condenser, in such order that the hottest steam comes in contact with the hottest condensing water; the next portion in contact with cooler water, and so on, until the last expansion is condensed with water of the temperature at which it can be obtained; a series of operations which, although strictly consecutive, may be conceived as being practically simultaneous. The injection-water entering the condenser at a temperature of 52° would issue from it at the boiling point, and be pumped from thence into the boiler at a temperature 92° higher than it attains in the usual manner, effecting a corresponding saving of fuel, besides accomplishing a more perfect condensation. With the aid of such an apparatus, it has been also suggested to render the present non-condensing engine partially condensing by the use of a very limited supply of condensing water, allowing part of the steam to escape in the usual way through the eduction or blast pipe, and to condense only the remaining volume of steam as at, or below, the atmospheric pressure.

The injection-water entering at 52° and issuing at 212°, would carry off from the steam 160 units of heat. Those portions of the steam which condense at 52°, or at other temperatures *below* 212°, act the part of *condensing water* in the successive compartments of the condenser, until finally the condensed steam issues from the last compartment at 212°. Consequently the condensed steam merely gives up its latent heat, 972 units (1152°—180°), and the proportion of condensing water to steam would be as 972 : 160, or as about 6 : 1.

Reverting, for the sake of illustrating the general case of a non-condensing engine, to the case of the locomotive with 12-inch cylinder, 18-inch stroke, and 5-ft. wheels, we have seen that the weight of steam passing through the cylinders per mile for neutralising atmospheric pressure was 57·26 ℔s. To condense this ($57 \cdot 26 \times 6 = 344$ ℔s. or) 35 gallons of water per mile would be required. Supposing the engine to be working with a load equivalent to a *total* pressure of four atmospheres on the pistons, the water evaporated to supply steam of that pressure would be, exclusive of waste, (1562 cubic feet of steam divided by 474, the relative volume of steam at that pressure to its producing water, $= 3 \cdot 3$ cube feet, or) about 20 gallons per mile. The boiler would be supplied with 20 gallons per mile (plus whatever might supply waste) from the water at boiling point derived from the condenser, and the remaining 15 gallons (or less) of heated water would go to waste. If such an additional supply

of water could be maintained without inconvenience, the advantages resulting would be—

1st, An increase of effective power in the engine in the ratio of 3 atmospheres to 4 atmospheres, for the *same* quantity of water evaporated or fuel used, irrespective of any benefit from expansive working.

2ndly, The opportunity of working the steam expansively to a greater extent than has hitherto been practicable.

3rdly, That the boiler is fed with hot water.

SECTION II.—PRACTICAL OBSERVATIONS ON RESISTANCES TO RAILWAY TRAINS.*

Resistances on the Narrow Gauge.

Table VII. (p. 533) is taken from Mr. Wyndham Harding's Paper 'on the Resistances to Railway Trains at different Velocities.'—(*Vide* article 'Railway,' p. 241.) This Table contains very full explanatory data to each experiment, which are not necessary for general information; but those who are desirous of fully investigating the subject for themselves should refer to the original Paper for full details of the summary given in the present Table.

The formula based on these experiments, furnished by Mr. Scott Russell, was adopted by Mr. Harding, "simply as an empirical formula, in order to see how far it agreed with the facts furnished by experiments made, as has been explained, by different persons at different times," and is thus described by Mr. Harding:

"The formula is very simple, and is based on the doctrine of the causes of resistance to the advance of railway trains being divisible into three classes.

"The first class of resistance is what is understood by friction, and is constant at all velocities.

"The second class is what is understood by frontage resistance, and increases as the square of the velocity in miles per hour, the resistance at one mile per hour being $\frac{1}{400}$ lb. per square foot of frontage.

"The third class of resistances may be termed, for want of a better word, resistances from concussion: the existence of such a class of resistances is indicated by the concussions and vibrations clearly perceived by a train in rapid motion. This class of resistances is held to vary in the simple ratio of the velocity.

"Calling the friction 6 lbs. per ton, the number of tons weight of the train = T, the velocity of the train in miles per hour = V, the resistance per square foot of frontage at 1 mile per hour = ·0025 lb., the resistances from concussions in pounds per ton of the load at 10 miles per hour and above = $\frac{V}{3}$†, the number of square feet in the frontage of the train = N; the formula giving the resistance in pounds per ton (of the weight of the train) is

$$6 + \frac{V}{3} + \frac{(V^2 \times \cdot0025 \times N)}{T}.$$

"The results which this formula gives are shewn in the last column of the Table. When an engine runs with a train, the friction of the engine is taken at 15 lbs. per ton of its weight.

"It will be seen that the results of the formula are somewhat higher than those of the experiments at the lower velocities, for which it is not difficult to account. In the higher range of velocities, where the formula is better tested, its agreement with the experimental results is very close.

* From a paper by Mr. John Sewell, C.E.

† The divisor 3 is assumed.

"It appears that it applies well to passenger trains from 20 tons to 64 tons weight, and from 30 to 60 miles an hour.

"Table II. affords the means of readily obtaining the resistances in lbs. per ton (according to this formula) of trains of passenger carriages travelling at any speed between 10 miles and 61 miles per hour."

The method of applying this formula and Table II. will be best explained by examples.

Having the velocity, weight in tons, and frontage in square feet given,—to find the resistance.

1st. Multiply the weight in tons by 6 lbs. for friction resistance.

2nd. Multiply one-third of the velocity by the weight of the train in tons, for the concussion resistance.

3rd. Multiply the square of the velocity by ·0025 lbs., and multiply that product by the number of square feet of frontage, for the atmospheric resistance.

4th. Add together these three resistances, and divide the sum by the weight of the train in tons, which will give the resistance in lbs. per ton.

Ex.—Taking a train of $21\frac{1}{2}$ tons, with a frontage of 60 square feet, and a velocity of 35 miles per hour,—required the resistance in lbs. per ton?

$$\begin{aligned} &\text{Weight } 21{\cdot}5 \times 6 \quad . \quad . \quad . \quad &= 129 \quad &= \text{friction resistance.} \\ &\text{Velocity } \tfrac{35}{3} \times 21{\cdot}5 \quad . \quad . \quad &= 249{\cdot}4 &= \text{concussion resistance.} \\ &\text{Frontage } 60 \times {\cdot}0025 \times 35^2 &= 183{\cdot}7 &= \text{atmospheric resistance.} \end{aligned}$$

$$\frac{\text{Total resistance} = 562{\cdot}1}{\text{Weight in tons} = 21{\cdot}5} = 26{\cdot}1 \text{ lbs. per ton.}$$

To find the horse-power of the engine.—Multiply the total resistance (just found) by the velocity of the train in feet per minute, and divide by 33,000, which will give the horse-power.

By Table I.—At a speed of 35 miles an hour, the velocity is 3080 feet per minute: hence total resistance $= \frac{562{\cdot}1 \times 3080}{33000} = 52{\cdot}46$ horse-power.

By Table II. this operation is readily performed.

Taking the same data as last example, and referring to the Table for 35 miles an hour, we find it is not given; but the mean between 34 and 36 miles will be sufficiently correct for our purpose, and it gives 17·6 lbs. for friction and concussion resistance. For atmospheric resistance the mean is 30·6 lbs. per square foot. Hence $\frac{30{\cdot}6 \times 60}{21{\cdot}5} = 8{\cdot}5$ lbs. per ton for atmospheric resistance, which, added to 17·6 lbs., gives 26·1 lbs. per ton of resistance, as before.

For horse-power, $\frac{26{\cdot}1 \times 21{\cdot}5 \times 3080}{33000} = 52{\cdot}46$ horse-power, as before.

This Table, therefore, facilitates the various calculations of resistances as found by Mr. Scott Russell's formula.

To prevent misunderstanding, it will be best to quote Mr. Harding's observations. He says, "Engineers are particularly reminded, that the resistances of which the present Paper treats must be understood to be the resistances, in calm weather, of engines and carriages of the ordinary construction, in good repair, on a railway also in good repair.

"In actual practice, various circumstances will arise, as side winds, want of repair, or adjustment in the carriages or road, sharp curves, &c.; all which tend to make the resistances more than the experiments shew."

Resistances on the Broad Gauge.

Various experiments made to ascertain the resistances to railway trains at different velocities were conducted by Mr. D. Gooch on the Bristol and Exeter Railway, in order that he might answer the queries sent to him, and also to other Engineers, by the Railway Commissioners.

Messrs. Stephenson, Locke, M'Connell, and Trevithick, in their replies on this point, referred to Mr. Wyndham Harding's Paper "On Resistances to Railway Trains," already explained; but Mr. D. Gooch instituted and carried out that valuable set of experiments published with full details in the Appendix to the Railway Commissioners' Report to the House of Lords on Railway Communication between London and Birmingham.

In these experiments are given, separately, the resistance due to the train, and the resistance due to the engine and tender preceding the train. This is an important step towards obtaining an accurate formula for estimating the resistances to railway trains of different weights and at different velocities.

The advantage of separating the engine and tender resistance from that of the train, in any general formula, will be evident by comparing its effects per ton on trains of different weights.

For instance, taking two of the experiments in Table III., at nearly the same velocity, but with different loads, we have for 100 tons, at 56·6 miles per hour, the engine and the tender resistance $= \frac{2469}{149 \cdot 2}$ lbs. $= 16 \cdot 5$ lbs. per ton over the gross weight of the train. For the 50 tons train, at 58 miles an hour, the engine and tender resistance $= \frac{2085}{100 \cdot 7}$ lbs. $= 20 \cdot 7$ lbs. per ton over the gross weight of the train.

A similar effect is produced on trains at low velocities. For 100 tons, at 21·1 miles an hour, we have engine and tender resistance $= \frac{807}{150 \cdot 8}$ lbs. $= 5 \cdot 3$ lbs. per ton; and for 50 tons, at 21·8 miles per hour, the engine and tender resistance $= \frac{973}{98 \cdot 5}$ lbs. $= 9 \cdot 8$ lbs. per ton.

It appears from this that the effect is about 4·2 lbs. per ton for the high velocity, and 4·5 lbs. per ton at the low velocity, greater resistance from the engine, over the weight of the light train than over that of the heavy one.*

The great amount of power absorbed by the engine itself is quite prominent throughout the whole of these experiments. Column 4, Table III., shews the resistance of the engine and tender considered as part of the train. Column 5 shews the estimated resistance of the machinery of the engine after deducting the resistance due to the engine and tender at the ratio of the train resistance.

The resistance of the machinery, however, admits of explanation. The connecting rods are of considerable weight, and freely suspended between the crank and cross-head. With a 2-feet stroke (that of the 'Iron Duke' class), the heavy end of the connecting rod travels through a space of 6·283 feet each revolution of the wheel, and for two connecting rods gives 12·566 feet for each revolution; while the other ends of the connecting rods travel about 8 feet during the same time. 72 miles an hour is about the maximum speed of this class of engines with a moderate load. The

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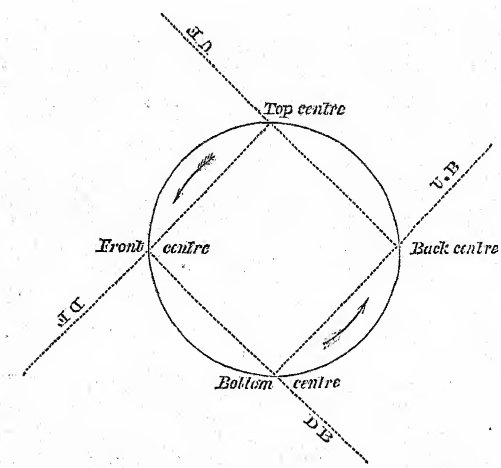
* In the comparative Diagram of Resistances accompanying Mr. D. Gooch's experiments this is clearly shewn, and is the reason why the lines of resistance of the 50 tons trains are higher than those for the 100 tons trains.

driving wheels are 8 feet diameter, and the stroke being 2 feet, gives the average velocity of the piston as 1000 feet per minute. The irregular motion of the crank will, however, make the velocity of the piston in the centre of the cylinder about 1500 feet per minute. The crank has at the same moment its greatest power, and the piston its greatest velocity, when the unbalanced centrifugal power and momentum of the connecting rod and crank change the direction of their forces. For instance, if the crank be on the top centre, and suppose that part of the connecting rod, with the crank to which it is attached, weighs no more than 560 lbs., we have this weight descending in a forward direction for 1·57 ft., and for the next 1·57 ft. descending in a backward direction, at an average velocity of 1575 feet per minute. Now if the weight is multiplied by the velocity, it gives 882,000 lbs. of mixed forces of momentum of the connecting rod and centrifugal force of the crank, changing the direction of its forces no less than eight times for each revolution of the driving wheel. As there are two connecting rods and cranks in motion to produce one revolution, consequently it requires two downward and forward, two downward and backward, two upward and backward, and two upward and forward changes of the direction of the forces generated by the combined movements of the crank and connecting rod. The dotted lines of the annexed diagram will shew what is meant by the different directions of the centrifugal force of the connecting rod and crank. The arrows indicate the direction in which the crank is moving, and the letters the direction of the forces. D F = downward and forward. D B = downward and backward. U B = upward and backward. U F = upward and forward.



The above estimate and diagram are given for illustration only, as it requires correct data to estimate the resistance accurately; but they will give an idea of the nature of the resistance to be overcome at high velocities, above that of the blast and slides.

When a locomotive piston travels at the average rate of 1000 feet per minute, the power absorbed by the unbalanced momentum of the machinery must be very considerable, and, far more than the resistance of the atmosphere, limits the velocity attainable by any class of engines. Practical men have long sought to find a remedy for this unbalanced momentum; and the higher the velocity, the more desirable it is that the piston and rod, the connecting rod and slide valves, should all be properly balanced.

Mr. Heaton, Mr. D. Gooch, and Mr. M'Connell were for some time engaged with experiments on this subject; and it was hoped that they would ultimately succeed in devising a practical remedy for the unbalanced machinery of a locomotive engine.

In practice it is found that the height of the driving wheel, other circumstances being alike, decides the average speed for each class of engines. This may be taken as proof that it is the resistance of the machinery which limits the speed, and that by giving it more ease, an increased standard of velocity is attained, corresponding to the ease given. Accordingly, Mr. Stephenson, in his 8-wheeled class of engines, adopts a 7-feet wheel, and Mr. Crampton, in his patent 8-wheeled engines, still further carries out the same principle by adopting an 8-feet wheel with a low centre of gravity, both necessary and desirable means for obtaining steadiness, speed, and safety on any railway.

Those who have travelled on locomotives at high velocities could scarcely fail to notice the rapid movements of the working parts of the engine without reflecting on the great power required to produce and sustain that movement itself, independent of load. To them, the above explanation of the supposed cause of resistance will be clearly understood. To others, who may not have had such an opportunity, an example will best explain it, and perhaps be the means of drawing both theoretical and practical attention to ascertain the value of such resistance, including the slide valves, the blast pipe, and compressed steam at high speeds. The 'Emperor' locomotive (one of the 'Iron Duke' class) travelled from Didcot to Paddington, a distance of 53 miles, with the ordinary express train, in 49½ minutes. The 'Great Britain,' with which the experiments referred to were made, is said to have run the same distance in 47½ minutes with the express train. The speed, therefore, was not an extreme one throughout, as no effort was made to obtain a high speed, but the engine was worked in the ordinary way.

The day was calm, but cloudy, and a higher speed was expected along the good straight road from Twyford to Maidenhead, but it was comparatively little increased. The steam was blowing off, and the fire-door was opened to check it. There was no side wind, for it was in a cutting, and the only atmospheric resistance was that due to the velocity. The load was about 60 tons: the speed was at the rate of from 70 to 72 miles an hour—a high speed, it is true, but the question immediately suggested itself,—Why, under such favourable circumstances, was the speed not higher?—eliciting only another question,—Where lay the limiting resistance to a higher speed? for there was clearly an equilibrium between the power and the resistance. The answer which occurred was this,—that it was the unbalanced machinery, the unbalanced slide valves, the effects of the blast, and of the steam compressed in the cylinder, which mainly limited the speed to 72 miles an hour.

If this be a correct view of the limiting cause of the speed of locomotive engines, it follows that increased velocities must be sought for by giving greater ease to the machinery, along with increased boiler and cylinder power. The investigation of Mr. D. Gooch's experiments seems to confirm this conclusion, and it is submitted now with the view of drawing the attention of future experimenters to determine its value as a principal resistance to railway trains at high velocities.

In submitting, therefore, an abstract of Mr. D. Gooch's experiments, the practical question has been kept clear from all other considerations, and the indicator and dynamometer resistances only investigated: these, being taken by competent and impartial persons, are valuable as data of resistances to railway trains under similar circumstances. The shortness of the distance experimented upon is the only drawback, but it renders the minutest error visible in the tabulated results in the Report to the House of Lords; and where these were observable, they have been omitted in taking the averages given in Table III. As the weather was very unfavourable for experimenting when they were made, they may be fairly regarded as giving average resistances on a calm day, and everything in good working order.

In Table III. the indicator and dynamometer resistances are given separately for the engine and train, and combined for the gross load. The first twelve columns are practical, and the headings will explain them : the next two columns are explanatory of the circumstances occurring when the experiments were made : the last nine columns are theoretical, calculated from a formula which will now be explained.

The resistance for the engine and tender, it will be observed, increases in the ratio of the velocity, regulated, however, by the load. Commencing at $5\frac{1}{2}$ lbs. per ton at 1 mile an hour, the ratio of the increase is ·5 lb. per mile per hour. From this we have the velocity $\times$ ·5 + 5 = resistance of engine and tender per ton for their own separate resistance. The additional resistance to the engine from the atmosphere and load is taken as the square of the velocity $\times$ by the weight of the train, and by ·00004, to be added to the preceding for the resistance per ton, and multiplied by their weight for the total resistance of the engine and tender in lbs. It may be thus stated :

Velocity $\times$ ·5 + 5 + velocity^2 $\times$ weight of train $\times$ ·00004 = engine and tender resistance per ton.

By this formula columns 19 and 22 are calculated.

The atmospheric resistance is taken as increasing in the ratio of the square of the velocity in miles per hour, regulated by the bulk of the train.

Messrs. W. Harding* and D. Gooch have both adopted Pambour's theory of frontage as the measure of atmospheric resistance. Regarding, however, the experiments made by Dr. Lardner for the British Association as more satisfactory than those made by Pambour, and the conclusions † of Dr. Lardner as supported by his experiments, they have been adopted in investigating Mr. D. Gooch's experiments.

By combining the bulk and velocity together in estimating the resistance of the atmosphere, results are obtained which vary with every varying load and speed, thereby fairly representing the displacement of air by railway trains of all dimensions.

For instance, the train with which these experiments were made, as shewn on the drawing accompanying them in the Railway Commissioners' Report, measures 276 feet long, which corresponds with the average length of the carriages and intermediate spaces between them. Their width is 9 feet, and height of bodies $7\frac{1}{4}$ feet; this gives $276 \times 9 \times 7\frac{1}{4} = 18009$ cubic feet of bulk for 10 carriages weighing 100 tons. By rejecting the odd 9 feet, we have 180 cubic feet of bulk = 1 ton weight of passenger carriages.

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* Mr. Harding, although adopting the frontage estimate for the atmospheric resistance to trains, yet clearly pointed out in his Paper (page 34) the objection to this mode of estimating that particular resistance. He says in conclusion, on this point,—"This objection points to the necessity of taking into account, in comparing resistances per ton of different trains, the composition of the trains, the resistances of which are being compared, especially as to their bulk or specific gravity, and other similar circumstances. It is not, however, easy to see what unit or common measure could be used in such comparisons which would be so convenient or intelligible to engineers as the ton weight." This unit I have endeavoured to supply by the actual data of 180 cubic feet of bulk being equal to one ton in weight for passenger carriages on the broad gauge. The same unit will be nearly correct for the narrow-gauge passenger carriages also.—J. S.

† After making a number of experiments with various sized and shaped vehicles, Dr. Lardner's conclusions on atmospheric resistance were,—

"That the shape of the front or hind part of the train has no observable effect on the resistance.

"That the spaces between the carriages of the train have no observable effect on the resistance.

"That the train, with the same width of frontage, suffers increased resistance with the increased bulk or volume of the coaches."

There is so little difference in the proportion of bulk to weight of carriages on both gauges, that the same ratio will, without material error, apply to both. The following average dimensions and weights, taken from Mr. D. Gooch's evidence as given in the Gauge Commissioners' Report, will shew how nearly they are alike. The height of the bodies only has been taken, as any atmospheric resistance to the wheels is more properly included with friction and oscillation.

	Average No. of passengers per carriage.	Weight of passengers, at $1\frac{1}{2}$ cwt. each.	Average weight of carriages.	Average weight of loaded carriage.	Average dimensions of carriages.			Average bulk in cubic feet of one carriage.	Average bulk per ton.
					Length.	Width.	Height.		
	No.	cwt.	cwt.	cwt.	feet.	feet.	feet.	cub. ft.	cub. ft.
Broad gauge	52	78	147	225	$25\frac{1}{2}$	9	$7\frac{1}{4}$	1664	147·9
Narrow gauge	21	$31\frac{1}{2}$	$80\frac{1}{2}$	112	17	7	7	833	148·8

The spaces between the carriages make up the difference shewn by the tabular bulk per carriage, and that obtained per carriage when forming part of a train. Until a more careful inquiry shall determine a better ratio, the approximation of carriages on both gauges is so near, that 180 cubic feet per ton might be tried for the narrow gauge as well as for the experiments to which it is now applied.

Independent, however, of Dr. Lardner's conclusions it is reasonable to assume that a train of the bulk of 18,000 cubic feet would experience greater atmospheric resistance than a train of only one-tenth of that bulk. This, however, is not recognised in the frontage theory, which, to make up for its apparent deficiency, even in the Comte De Pambour's experiments, included wheels, the eddying between the carriages, and (if it were fully carried out) should also have included the resistance from every open carriage-window in a train. By taking the bulk for the measure of atmospheric resistance, it embraces all these in a much more satisfactory manner than can be done separately, and for these reasons it has been adopted at this time in investigating the broad-gauge experiments.

The atmospheric resistance is therefore taken to increase in the ratio of the square of the velocity in miles per hour × by the bulk of the train in cubic feet, and by ·00002 as a co-efficient per ton of train. By this data column 16 is calculated.

The friction resistance is taken at 6 lbs. per ton, as seen in column 15.

The oscillatory resistance is taken as increasing in the ratio of $\frac{1}{15}$th the velocity × by the weight of the train only. Column 17 is calculated by this data.

For what reason experimenters separate these two last resistances does not clearly appear. They are evidently the same resistance, increasing in the ratio of the velocity only. Oscillatory resistance is mainly the increased friction of the axle bearing against the collars of the axle, consequent upon the transverse vibrations at high velocities. It is practically and forcibly exhibited in the wearing away of the ends of the axle bearings, which in many instances wear more rapidly than the top part where the weight rests upon. The bearing has then to be lengthened, or thrown aside as old metal.

Such practical evidence is the strongest proof that the axle friction is not constant at all velocities, but increases with the increasing velocity, and should be so estimated generally, as in Table IV. and in the 'Diagram of Resistances.' (*See* Plate.)

In Table III. they have, however, been given separately, the better to test the formula, and also as an unit to start from, adopted by former experimenters and investigators of resistances to railway trains.

The formula, therefore, by which the estimated resistances in Table III. and IV. are calculated is submitted as an empirical one only, and embraces,—

1st, The engine and tender resistance, increasing in the ratio of the velocity for their own resistance, and in the ratio of the square of the velocity, regulated by the load, for atmospheric and load resistance.

2ndly, The atmospheric resistance of the train, increasing as the square of the velocity, regulated by the bulk of the train.

3rdly, The oscillatory resistance, increasing in the ratio of the velocity (estimated at one-fifteenth), regulated by the load.

4thly, The friction resistance (for the reasons given, estimated at 6 lbs. per ton), regulated by the load.

It is, therefore, simple in its elements, and may be thus expressed.

Calling the weight of the train in tons $= T$, the friction of the train per ton $= 6$ lbs., the bulk of the train in cubic feet $= B$, the weight of the engine and tender $= E$, the velocity $= V$; we have for a formula by which to estimate the resistances separately,

$$E \times (V \times \cdot 5 + 5 + V^2 \times T \times \cdot 00004) = \text{engine and tender resistance in lbs.}$$

$$V^2 \times B \times \cdot 00002 \ldots\ldots = \text{atmospheric resistance in lbs.}$$

$$\frac{V \times T}{15} \ldots\ldots = \text{oscillatory resistance in lbs.}$$

$$T \times 6 \ldots\ldots = \text{friction resistance in lbs.}$$

These separate resistances, being added into one sum and divided by the gross load, give the estimated resistance per ton. Briefly it would stand thus :—

$$E \times (V \times \cdot 5 + 5 + V^2 \times T \times \cdot 00004) + (V^2 \times B \times \cdot 00002) + \frac{V \times T}{15} + \frac{T \times 6}{E.T.}$$
= resistance per ton.

The theoretical resistances given in Table III. are from the above formula, and their general agreement with the (somewhat irregular) practical results is satisfactory.

Table IV. is also drawn up from this formula, to facilitate estimating the resistances of trains under similar circumstances on a level line, a calm day, and engine, carriages, and road in good working order.

The Diagram * shews the same resistances as Table IV., exhibiting them separately for the engine and train. For the reasons already mentioned, lines of resistance for the engine and tender, with various loads, are also shewn separately. Being divided into tenths of an inch each way, either miles or lbs. can be counted without the aid of a scale or instruments. The base line indicates the velocity in miles per hour. The vertical lines indicate the lbs. per ton at the point intersected by the line of resistance. Each tenth of an inch along the base line represents one mile, and each tenth of an inch on the vertical lines represents 1 lb.

As the additional resistance from the atmosphere and load on the engine and tender is only 2·25 lbs. per ton of the train, at a velocity of 75 miles an hour, it is shewn in a separate diagram, where the miles on the base line are represented by tenths of an inch; but the lbs. on the vertical lines by hundredths of an inch. This admits the resistance in hundredths of a lb. per ton to be counted without the aid of instruments. The resistance in lbs. per cubic foot of bulk is one-half of this additional resistance.

* Owing to the small scale of the Diagram, there is some irregularity in the train lines D, which is accidental, and not the result of the theory; but Table IV. gives them correctly in figures.

The results arrived at in this investigation, and embodied in the diagrams, demonstrate the necessity of a more perfect mechanical construction of the locomotive engine, and fully explain what has been stated regarding the vast amount of power absorbed by the engine itself.

The application of the Formula and Tables will now be explained by examples, as before.

Having the velocity, weight of engine and tender in tons, weight of train in tons, and bulk of train (exclusive of engine and tender) in cubic feet, given,—required the engine and tender resistance, the atmospheric resistance, the oscillatory resistance, and the friction resistance, separately; also per ton of the gross load?

1st, Multiply the velocity by ·5, and to the product add 5 for the friction of the axles and machinery of the engine. For the additional resistance of the atmosphere and load on the engine, multiply the square of the velocity in miles per hour by the weight of the train in tons, and by ·00004. Add these together for the resistance in lbs. per ton of the engine and tender, and multiply by their weight in tons for their total resistance in lbs.

2ndly, Multiply the square of the velocity by the bulk of the train (excluding the engine and tender), and by ·00002, for the atmospheric resistance in lbs. due to the train.

3rdly, Multiply the velocity by the weight of the train, and divide by 15, for the oscillatory resistance of the train in lbs.

4thly, Multiply the weight of the train in tons by 6, for the friction resistance in lbs.

5thly, Add into one sum these resistances, and divide by the gross weight of the train in tons, for the resistance in lbs. per ton of the gross load.

Ex.—Taking a train of 100 tons, engine and tender of 49·2 tons, velocity 56·6 miles per hour, and bulk 18,000 cubic feet,—required the separate resistances, and the resistance per ton of the gross load? (See Table III.)

For the engine and tender resistance we have

$$56{\cdot}6 \times {\cdot}5 + 5 + 56{\cdot}6^2 \times 100 \times {\cdot}00004 = 46{\cdot}1 \text{ lbs. per ton} \times 49{\cdot}2 = 2268{\cdot}12 \text{ lbs.}$$

resistance for the engine and tender.

In order to test the formula, it will be contrasted, throughout this example, with the experimental results. On referring to the Table it will be observed that the experimental resistance is greatest by 201 lbs. As the train was, however, subjected to a 'strong side wind,' the whole of the experimental results are greater than those found by the formula. In other instances the resistances found by the formula are greatest. It is, therefore, by its general agreement with the whole of the experiments that it should be tested, and not by any one experiment. The example now taken shews a total difference of 251 lbs.; 201 lbs. of which are due to the engine, or about 4 lbs. per ton on the engine and tender weight, shewing that although the resistance of the engine is estimated at a high rate, it does not appear to be in excess for ordinary contingencies, being too low for the effects of a side wind on the engine.

For the friction resistance we have $100 \times 6 = 600$ lbs. This, taken from the dynamometer resistance of 2180 lbs., leaves 1580 lbs. to be divided between the atmospheric and oscillatory resistances, and so limits the inquiry as to admit of no great error in estimating them.

For oscillatory resistance we have $\frac{56{\cdot}6 \times 100}{15} = 377{\cdot}3$ lbs., which, taken from 1580, leaves 1202·7 lbs.

For atmospheric resistance we have $56{\cdot}6^2 \times 18000 \times {\cdot}00002 = 1153{\cdot}28$ lbs., or 49·4 lbs. less resistance for the train by formula than by the dynamometer, being

within half a pound per ton of the weight of the train, although exposed to a side wind.

Stated concisely, these calculations would stand thus :

	lbs.	Resistances.
$56{\cdot}6 \times {\cdot}5 + 5 + 56{\cdot}6^2 \times 100 \times {\cdot}00004 \times 49{\cdot}2$	$= 2268{\cdot}12$	= engine and tender.
100×6	$= 600$	= friction.
$\dfrac{56{\cdot}6 \times 100}{15}$	$= 377{\cdot}3$	= oscillatory.
$56{\cdot}6^2 \times 18000 \times {\cdot}00002$	$= 1153{\cdot}28$	= atmospheric.

$$\text{Gross weight of train} = \frac{4398{\cdot}7}{149{\cdot}2} = 29{\cdot}48 \text{ lbs.}$$

per ton of the gross load.

The experimental resistance was 31·16 lbs. per ton, the estimated resistance 29·48 lbs., or 1·68 lb. per ton of the load less than the former ; a near approximation to a train having the retarding influence of a side wind to contend against, with four-fifths of this difference due to the engine.

The formula, therefore, from which this estimate, Table IV., and the Diagram, are drawn up, appears to be sufficiently accurate for general reference for engines and trains on the broad gauge of the class experimented with by Mr. D. Gooch.

As these experiments were made with an engine and tender weighing about 50 tons, with 8-feet driving wheels, the line of engine and tender resistance per ton on the diagram will only apply to engines of the same general class and weight. The greater ease to the machinery of an engine with 8-feet driving wheels over that of an engine with 5, $5\frac{1}{2}$, or 6-feet wheels, is necessarily very considerable, as seen below.

By Table VI. the revolutions of an 8-feet wheel per mile are 210·1 times,—of a 6-feet wheel 280·5 times,—of a $5\frac{1}{2}$ feet wheel 305·6 times,—and of a 5-feet wheel 336·3 times ; consequently, for a run of only 50 miles, it gives

	Revolutions of the driving wheel.		No. of the cylinders of steam to exhaust through the blast pipe.
For an 8-feet wheel	$210{\cdot}1 \times 50 = 10505$	or	42020
,, 6-feet ,,	$280{\cdot}5 \times 50 = 14025$	or	56100
,, $5\frac{1}{2}$-feet ,,	$305{\cdot}6 \times 50 = 15280$	or	61120
,, 5-feet ,,	$336{\cdot}3 \times 50 = 16815$	or	67260

As the resistance of the machinery, slides, and blast increases rapidly in proportion to the velocity of the piston and the number of exhausts of steam per minute, the line which indicates the $\frac{1}{30}$th of the resistance due to the complete machine for generating power, with its machinery moving $\frac{1}{3}$, $\frac{1}{2}$, or $\frac{3}{5}$ slower than the working parts of another power-producing machine, it is evident, would not indicate $\frac{1}{50}$th of the resistance due to the more rapid moving machinery of a lighter machine. The ratio of the resistance for the latter machine would therefore be much higher than $\frac{1}{50}$th of that due to the 'Great Britain' class of engines.

That the machinery of the 'Great Britain' works freely is beyond question. Twice, with the ordinary express trains, this engine maintained an average velocity of nearly 67 miles per hour over the 53 miles from Paddington to Didcot, including starting from a state of rest until coming to the stopping platform again. The one trip was up gradients averaging 4 feet per mile, the other down the same gradients. The trip up the gradients is generally run in least time : this arises from having to reduce the speed quite low on the down trip, nearly a mile from Paddington, which thus takes much longer time to run over than is fairly due to stopping at any other station.

Sixty-seven miles an hour is about the maximum average velocity of the 'Iron Duke' class of engines. The 'Great Britain' was made from the same drawings as the 'Iron Duke,' and the performances of the whole class are as nearly alike as those of any class of engines can be. A new class of engines of the same general construction, but with 3 inches shorter tubes and 6 inches longer fire-box, appear, from the performance of the 'Courier' (one of the new class), as reported in the *Morning Herald* (although only newly out of the shop), to have equalled the 'Iron Duke' class. As the area of the blast pipe of the 'Courier' class is larger by about 4 square inches than the blast pipe of the 'Iron Duke' class, it shews that the enlarged fire-box generates the same quantity of steam with less blast; and as the increased size of the blast pipe diminishes the compression, it so far eases the piston that a proportionally increased velocity will be attained, with less consumption of fuel, from the milder blast on the fire. This consumption is as low as from 24 to 26 lbs. of coke per mile for running 1078 miles per week with the mail trains, and that for engines newly out of the workmen's hands.

Regarding, therefore, 75 miles an hour as the maximum velocity of the best locomotive engines of the day, the Table No. IV. and the Diagram of Resistances from the formula have been carried out to that velocity only. When a higher velocity is attained, it will be by some improved arrangements of the machinery, slide valve, and blast, which would give a lower ratio of resistance throughout, and require new data to indicate the new line of resistance due to the superior arrangements of the power-producing machine.

The line of resistance, therefore, which is applicable to the 'Great Britain' class of engines cannot be applicable to other classes of engines (irrespective of gauge), as from this investigation it appears that each different kind would have its own separate line of resistance. As there is not so great variety amongst carriages as amongst engines, the ratio of resistance for the carriages would be more permanent than it can be for engines so variously constructed.

The data for indicating the lines of resistance for locomotives of various descriptions are extremely limited. The Comte de Pambour clearly saw, and ably pointed out, the necessity of estimating the resistances separately. His experiments on the friction of loaded and unloaded engines were very good as far as they went, and only require to be fully carried out, to give the data necessary to lay down lines of resistance for any particular class of locomotives.

In the Diagram of Resistances the lines A and B indicate the mean resistance the Comte de Pambour found by experiment on engines from 8 to 11 tons weight; but he gives no data by which to trace the direction of these lines. The only other available data are those of two indicator experiments taken by Mr. D. Gooch, at 10 and 20 miles an hour. The line marked C on the diagram shews the resistance per ton indicated by these experiments. It is not given for calculating the resistance of the 'Ixion' class of engines, but is given along with the resistances indicated by the Comte de Pambour's experiments, as sufficient to shew that new experimental data are required to determine the law of resistance to locomotive engines of various descriptions on both gauges. One inference which may be drawn from the highest speed of the 'Iron Duke' and other classes of engines seems to be this, that with a load, and at a velocity of 1000 feet per minute of the piston, locomotives have reached their maximum velocity as they are at present (1848) constructed. This point, however, should be investigated by future experimenters, in order to deduce from it some general law applicable to the velocity of the piston, and its relation to the highest speed of locomotives of various constructions.

From what has been said, it will be clearly understood that the resistances indi-

cated by the formula are those due to engines of the class of the 'Iron Duke,' and carriages of the ordinary construction on the Great Western Railway, both in good working order, on a calm day, and on a level railway in good repair. For gradients they require to have the resistance per ton due to the incline, as in Table V., added to the resistances given in Table IV. or in the Diagram of Resistances. For gradients not in Table V. the resistance due to the incline may be found by dividing the lbs. in a ton (2240 lbs.) by the ratio of the rise in feet. Thus, if the gradient be 1 in 700 feet, we have $\frac{2240}{700} = 3\cdot2$ lbs. per ton as the resistance due to the incline, to be added to the resistance given by the formula.

With these observations we now proceed with the examples.

By Table IV. the resistances given by the formula are readily calculated.

Ex.—Required the total resistance, and the resistance per ton of the gross load, for a train of 60 tons, engine and tender 50 tons, bulk of train 10,800 cubic feet, and velocity 50 miles per hour, on a level railway? Referring to the Table, opposite '50 miles per hour' is 30 lbs. for the engine and tender resistance, and ·1 lb. for the additional resistance to the engine from the atmosphere and load per ton of the train, or ·05 per cubic foot of bulk of the train. This gives for engine and tender resistance $60 \times \cdot1 = 6$ lbs., to be added to the 30 lbs. due to the engine and tender alone, $= 36$ lbs. per ton as the engine and tender resistance. For friction and oscillation the resistance opposite '50 miles per hour' is 9·33 lbs., and for the atmosphere 9 lbs., hence

Engine and tender of 50 tons	×	36	lbs.	= 1800	lbs.	= { engine and tender resistance.
Train of 60 tons	×	9·33	,,	= 559·8	,,	= { friction and oscillation resistance.
,, of 60 tons	×	9·0	,,	= 540	,,	= { atmospheric resistance.

$$\frac{\text{Total resistance}}{\text{Gross weight of train}} = \frac{2899\cdot8}{110} = \left\{ \text{26·36 lbs. per ton of the gross load.} \right.$$

Or thus by bulk:

Engine and tender of 50 tons	×	36	lbs.	= 1800	lbs.
Train of 60 tons	×	9·33	,,	= 559·8	,,
,, bulk of 10,800 cubic feet	×	·05	,,	= 540	,,

$$\frac{\text{Total resistance}}{\text{Gross load}} = \frac{2899\cdot8}{110} = 26\cdot36 \text{ lbs. per ton, as before.}$$

By taking the total resistance of the train at once it shortens the calculation.

Thus, $50 \times 36 = 1800$

And for total resistance by Table

we have 18·33 lbs.; and $60 \times 18\cdot33 = 1099\cdot8$

$$\frac{\text{Total resistance}}{\text{Gross load}} = \frac{2899\cdot8}{110} = 26\cdot36 \text{ lbs., as before.}$$

For the resistance to the above train on a gradient of 1 in 100, requires to be added the gravity due to the incline, which by Table V. is 22·4 lbs. per ton; therefore $26\cdot36 + 22\cdot4 = 48\cdot76$ lbs. as the resistance per ton of a gross load of 110 tons, up a gradient of 1 in 100, at 50 miles an hour.

The Diagram of Resistances greatly facilitates the calculation of the resistances found from the formula, and, if constructed on a large scale, would do so with sufficient accuracy for all ordinary purposes.

Ex.—Taking the same data as last example,—required the resistance in lbs. per ton on a level railway, and calm day?

The velocity being 50 miles and the train 60 tons, by referring to the Table, and following the '50 miles' vertical line until it intersects the '60 tons engine and tender' line, we have 36 lbs., which, multiplied by the weight of the engine and tender, 50 tons, = 1800 lbs. Again, following the '50 miles' vertical line until it intersects the train line of resistance, we have $18\frac{1}{3}$ lbs., say 18·33 lbs. × 60 tons = 1099·8 lbs. + 1800 lbs = 2899·8 lbs. total resistance, divided by 110 tons (the gross load) = 26·36 lbs.

Another example will illustrate the facility with which this Diagram of Resistances can be applied.

Ex.—Required the resistance of a train of 70 tons, engine and tender 50 tons, at 60 miles an hour, on a level, also the resistance on a gradient of 1 in 800?

By the Table we find the '60 mile' vertical line intersects the '70 ton' engine and tender line at 45 lbs., and the train line at nearly 23 lbs. (by calculation 22·96 lbs.);

Therefore, Engine and tender of 50 tons × 45 lbs. = 2250 lbs.
and Train of 70 tons × 23 lbs. = 1610 ,,

$$\text{Divided by the gross load} = \frac{3860}{120}\left\{\begin{array}{l}\text{tons, } = 32{\cdot}16 \text{ lbs. per} \\ \text{ton, on a level.}\end{array}\right.$$

For the gradient, by Table V. the resistance due to 1 in 100 is 22·4 lbs.; hence 22·4 ÷ 8 = 2·8 lbs. as the resistance per ton due to a rise of 1 in 800; and 32·16 + 2·8 = 34·96 lbs. per ton on a gradient of 1 in 800.

Resistance of the Blast Pipe.

As the blast pipe is a distinct and important part of a locomotive engine, we will now endeavour to ascertain its practical value for engines of the class of the 'Great Britain.'

The resistance of the blast pipe was deducted from all the experiments recorded in Table III. In addition, therefore, to the resistances already considered, the steam has to overcome that of the blast pipe. The indicator cards taken during these experiments, as given in Table VIII., supply valuable data of the relations between front and back pressure, also between the load, the velocity, and the pressure on the piston. From this record of 67 indicator cards, it appears that the back pressure follows the ratio of the mean pressure on the piston, regulated by its velocity; and that whilst a heavy load increases the mean pressure on the piston, the per-centage of back to front pressure remains nearly the same as with lighter loads at similar velocities.

The pressure of the steam in the boiler will regulate that of the steam admitted to the cylinder until the communication is cut off by the slide valve. The degree of expansion of the steam so cut off will then regulate the mean pressure on the piston so that it may be generated under a pressure of 90 lbs. in the boiler, and only averaging 20 lbs. in the cylinder. It is therefore the lbs. of steam cut off in the cylinder which regulate the resistance of the blast pipe; for if it be expanded during three-fourths of the stroke, a low back pressure will result; but if only expanded during one-fourth of the stroke, a higher back pressure will be produced,—so that the mean pressure on the piston indicates the degree of expansion in the cylinder. The general increase being nearly in the ratio of the square of the pressure, it has been so estimated in the law for calculating the resistance of the blast pipe. The velocity of the piston in feet per minute, the orifice of the blast pipe, and the capacity of the cylinder, are the remaining elements of that law.

The formula (from which the theoretical columns of back pressure in the Table have been calculated) embraces all these in the following manner:

To the square of the mean pressure in lbs. per square inch + the velocity of the piston in feet per minute, × by the ratio of the capacity of the cylinder to the area of the orifice of the blast pipe, and by ·00001, for the back pressure in lbs. per square inch against the piston. If we call the pressure P, the velocity V, the ratio of the cylinder and blast pipe R, the formula would stand thus :

$$P^2 + V \times R \times \cdot 00001 = \text{back pressure in lbs. per square inch.}$$

It is submitted as an empirical law only, limited at present to engines of the class of the 'Great Britain,' until future experiments shall determine whether it is applicable to other classes of locomotives. Its application is simple, and will now be explained by an example.

Ex.—Let a locomotive engine have cylinders 18 inches diameter, 2-feet stroke, blast pipe 5 inches diameter, driving wheels 8 feet diameter, velocity 56·6 miles per hour, mean pressure on the piston 79·4 lbs. per square inch ; required the back pressure against the piston ? (See Table VIII.)

$$\begin{array}{l} \text{For capacity of cylinder we have } 18^2 \times \cdot 7854 \times 24 = \\ \text{For area of orifice of blast pipe we have } 5^2 \times \cdot 7854 = \end{array} \frac{6107 \cdot 25}{19 \cdot 635} = 311$$

for the ratio between the cylinder and blast pipe.

For the velocity of the piston we have by Table VI. 210·1 (revolutions for an 8-feet wheel per mile) × 4 = 840·4 feet travelled by the piston per mile ; hence 840·4 ÷ 60 = 14·0 as the ratio nearly between the miles per hour of the driving wheel and the feet per minute of the piston, and which has been adopted in calculating the resistances in Table VIII.

Therefore, $(79 \cdot 4^2 + 56 \cdot 6) \times 14 \times 311 \times \cdot 00001 = 22 \cdot 068$ lbs. per square inch for the back pressure.

By referring to the Table it will be seen that the experimental result was 22·5, so that the formula gives a near approximation to the practical value of the back pressure for engines of the class of the 'Great Britain.' It also gives results varying with every varying ratio of cylinder to blast pipe. Applied to some experiments made by Mr. J. Parkes,* it gives results nearly the same as he arrived at by removing the blast pipe. From these experiments Mr. Parkes concluded—"That the counter-resistance from the blast augments and diminishes with the pressure on the piston, and that it is independent of the velocity of the piston ; for in all these observations it only rose with the velocity when the pressure was increased."

The more extensive series of observations taken by Mr. D. Gooch confirm the first part of this conclusion, but show that it is modified by the velocity of the piston. As the Comte De Pambour does not give the pressure in the boiler or on the piston, during the experiments he made (regarding back pressure as due to velocity only), we cannot compare his experiments with the formula now submitted.

Mr. D. Gooch states that "in the 'Ixion' engine, the blast pipe of which was $\frac{1}{15}$th of the area of the cylinder, with the driving wheel 7 feet in diameter, and the steam cut off at $13\frac{5}{8}$ inches of the stroke, the loss from the back pressure at different velocities was 2·1 per cent. at 7 miles an hour ; 11·6 per cent. at 20 miles ; 15·8 per cent. at 40 miles ; and 21 per cent. at 60 miles ; and the indicator cards accompanying the Experiments on the Resistance of Trains also shew nearly similar results."

These cards, it has been seen, shew that the back pressure increases generally in the ratio of the pressure regulated by the velocity, and that the larger the orifice of the blast pipe is to the capacity of the cylinder, the less back pressure there will be at all velocities.

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* The ratio of the orifice of the blast pipe to the cylinder was $\frac{1}{474}$ in that case.

TABLES OF RESISTANCES TO RAILWAY TRAINS.

TABLE I.

Table of the Time occupied in running ¼, ½, ¾, *and* 1 *mile; also the Difference of Time in the Rates of Velocity per mile, and the Speed in feet per minute of the Engine or Train, from* 1 *to* 90 *miles an hour.*

SPEED per hour.	TIME OF RUNNING. ¼ mile.	½ mile.	¾ mile.	1 mile.	Difference of Time per mile.	Speed of Engine per min.*	SPEED per hour.	TIME OF RUNNING. ¼ mile.	½ mile.	¾ mile.	1 mile.	Difference of Time per mile.	Speed of Engine per min.*
Miles.	″	″	″	′ ″	″	Feet.	Miles.	′ ″	′ ″	′ ″	′ ″	′ ″	Feet.
90	10	20	30	40		7920	45	20	40	1 0·0	1 20	1·74	3960
89	10·11	20·22	30·33	40·45	·45	7832	44	20·45	40·90	1 1·35	1 21·81	1·81	3872
88	10·22	20·45	30·66	40·9	·45	7744	43	20·93	41·86	1 2·79	1 23·72	1·91	3784
87	10·34	20·68	31·02	41·37	·47	7656	42	21·42	42·85	1 4·28	1 25·71	1·99	3696
86	10·46	20·93	31·38	41·86	·49	7568	41	21·95	43·90	1 5·85	1 27·8	2·09	3608
85	10·59	21·17	31·76	42·35	·49	7480	40	22·5	45	1 7·5	1 30	2·20	3520
84	10·71	21·42	32·13	42·85	·50	7392	39	23·07	46·15	1 9·22	1 32·30	2·30	3432
83	10·84	21·68	32·52	43·37	·52	7304	38	23·68	47·36	1 11·05	1 34·73	2.43	3344
82	10·97	21·95	32·92	43·90	·53	7216	37	24·32	48·64	1 12·97	1 37·29	2·56	3256
81	11·11	22·22	33·33	44·44	·54	7128	36	25	50	1 15	1 40	2·71	3168
80	11·25	22·5	33·75	45	·56	7040	35	25·71	51·42	1 17·18	1 42·85	2·85	3080
79	11·4	22·7	34·17	45·57	·57	6952	34	26·47	52·94	1 19·41	1 45·88	3·03	2992
78	11·53	23·07	34 71	46·15	·58	6864	33	27·27	54·54	1 21·81	1 49·09	3·21	2904
77	11·68	23·37	35·06	46·75	·60	6776	32	28·12	56·25	1 24·37	1 52·5	3·41	2816
76	11·84	23·68	35·52	47·36	·61	6688	31	29·03	58·06	1 27·09	1 56·12	3·62	2728
75	12	24	36	48	·63	6600	30	30	1 0·00	1 30	2 0	3·88	2640
74	12·16	24·32	36·48	48·65	·65	6512	29	31·03	1 2·06	1 33·09	2 4·13	4·13	2452
73	12·32	24·65	36·98	49·31	·66	6424	28	32·14	1 4 28	1 36·42	2 8·57	4·44	2364
72	12·5	25	37·5	50	·68	6336	27	33·33	1 6·66	1 39·99	2 13·33	4·76	2376
71	12·67	25·35	38·01	50·7	·70	6248	26	34·61	1 9·23	1 43·83	2 18·66	5·13	2288
70	12·85	25·71	38·55	51·42	·72	6160	25	36	1 12	1 48	2 24	5·54	2200
69	13·04	26·08	39·12	52·17	·75	6072	24	37·5	1 15	1 52·5	2 30	6·0	2112
68	13·23	26·47	39·70	52·94	·77	5984	23	39·13	1 18·26	1 57·39	2 36 52	6·52	2024
67	13·43	26 86	40·29	53·73	·79	5896	22	40·90	1 21·81	2 2·72	2 43·63	7·11	1936
66	13·63	27·27	40·90	54·54	·81	5808	21	42·85	1 25·71	2 8·55	2 51·42	7·79	1848
65	13·84	27·69	41·53	55·38	·84	5720	20	45	1 30	2 15	3 0	8·58	1760
64	14·06	28·12	42·18	56·25	·87	5632	19	47·36	1 34·73	2 22·08	3 9·47	9·47	1672
63	14·28	28·57	42·85	57·14	·89	5544	18	50	1 40	2 30	3 20	10·53	1584
62	14·51	29·03	43·54	58·06	·92	5456	17	52·94	1 45·88	2 38·82	3 31·76	11·76	1496
61	14·75	29·50	44·25	59·01	·95	5368	16	56·25	1 52·5	2 48·75	3 45	13·24	1408
60	15	30	45	1 0	·99	5280	15	1 0	2 0	3 0	4 0	15	1320
59	15·25	30·50	45·75	1 1·01	1·01	5192	14	1 4·26	2 8·52	3 12·78	4 17·14	17·14	1232
58	15·51	31·03	46·54	1 2·06	1·05	5104	13	1 9·23	2 18·46	3 27·69	4 36·92	19·78	1144
57	15·78	31·57	47·36	1 3·15	1·09	5016	12	1 15	2 30	3 45	5 0	23·08	1056
56	16·07	32·14	48·21	1 4·28	1·113	4928	11	1 21·81	2 43·63	4 5·45	5 27·27	27·27	968
55	16·36	32·72	49·08	1 5·45	1·117	4840	10	1 30	3 0	4 30	6 0	33·73	880
54	16·66	33·33	49·99	1 6·66	1·21	4752	9	1 40	3 20	5 0	6 40	40	792
53	16·98	33·96	50·94	1 7·92	1·26	4664	8	1 52·5	3 45	5 37·5	7 30	50	704
52	17·30	34·61	51·90	1 9·23	1·31	4576	7	2 8·57	4 17·14	6 25·71	8 34·28	1 4·28	616
51	17·64	35·29	52·92	1 10·58	1·35	4488	6	2 30	5 0	7 30	10 0	1 25·72	528
50	18	36	54	1 12	1·42	4400	5	3 0	6 0	9 0	12 0	2 0	440
49	18·36	36·73	55·09	1 13·47	1·47	4312	4	3 45	7 30	11 15	15 0	3 0	352
48	18·75	37·5	56·25	1 15	1·53	4224	3	5 0	10 0	15 0	20 0	5 0	264
47	19·14	38·29	57·44	1 16·59	1·59	4136	2	7 30	15 0	22 30	30 0	10 0	176
46	19·56	39·13	58·69	1 18·26	1·67	4048	1	15 0	30 0	45 0	60 0	30 0	88

* For miles and fractions of a mile, multiply the speed given by 88 for the speed in feet per minute.

EXPLANATION.

Having the velocity given for ¼, ½, or ¾ of a mile,—required the rate of speed per hour?

Find the particular velocity of the one nearest to it under the proper column, and opposite to it, in the column 'per hour,' is the rate required.

Ex.—If the time in running ¼ of a mile is 16 seconds,—required the rate per hour?.

Ans.—Under the column '¼ mile' the nearest number is 16·07, and opposite to that number, in the 'per hour' column is 56 miles, the rate of speed required.

TABLE II.

Table to facilitate the Calculation of the Resistances to Passenger Trains on a calm day, on a level line, practically straight, the Rails and Carriages being in good working order, and generally in the absence of any disturbing cause calculated to affect materially the amount of resistance: calculated from Formula.

Velocity in miles per hour.	Resistance from friction.	Resistance varying as velocity.	Sum of the two resistances.	Resistance of the atmosphere per square foot of frontage of train.	Velocity in miles per hour.	Resistance from friction.	Resistance varying as velocity.	Sum of the two resistances.	Resistance of the atmosphere per square foot of frontage of train.
10	6	3·3	9·3	0·25	44	6	14·6	20·6	4·84
12	6	4·	10·	0·36	45	6	15·	21·	5·06
14	6	4·6	10·6	0·49	46	6	15·3	21·3	5·29
16	6	5·3	11·3	0·64	47	6	15·6	21·6	5·52
18	6	6·	12·	0·81	48	6	16·	22·	5·76
20	6	6·6	12·6	1·	49	6	16·3	22·3	6·
22	6	7·3	13·3	1·21	50	6	16·6	22·6	6·25
24	6	8·	14·	1·44	51	6	17·	23·	6·50
26	6	8·6	14·6	1·69	52	6	17·3	23·3	6·76
28	6	9·3	15·3	1·96	53	6	17·6	23·6	7·02
30	6	10·	16·	2·25	54	6	18·	24·	7·29
32	6	10·6	16·6	2·56	55	6	18·3	24·3	7·56
34	6	11·3	17·3	2·89	56	6	18·6	24·6	7·84
36	6	12·	18·	3·24	57	6	19·	25·	8·12
38	6	12·6	18·6	3·61	58	6	19·3	25·3	8·41
40	6	13·3	19·3	4·	59	6	19·6	25·6	8·70
41	6	13·6	19·6	4·22	60	6	20·	26·	9·
42	6	14·	20·	4·41	61	6	20·3	26·3	9·30
43	6	14·3	20·3	4·62					

"*Note.*—The correction for gravity on any given inclination is of course easily applied to the results of the formula. In cases of accelerating and retarding velocities a correction will be requisite, on account of part of the train being in rotatory motion.—(See Report of Mr. E. Wood, page 248 of 'Report of British Association, 1841.) It is scarcely necessary to caution Engineers, that in applying the results of such a Table as the above for practical purposes, care must be taken that the circumstances assumed, and necessarily so, in the formula suggested, coincide with the actual circumstances of the case to which it is sought to apply the formula."

For miles not in this Table, take the mean resistances between the two nearest mileages for the resistance due to the even miles per hour. Thus for a train of 18 tons at 21 miles an hour, and frontage 60 feet, take for 20 miles $\frac{12{\cdot}6+13{\cdot}3}{2}$ for 22 miles $=12{\cdot}95$ lbs. at 21 miles $\times$ 18 tons $= 233{\cdot}1$ lbs. for friction and concussion resistance. For atmospheric resistance we have $\frac{1+1{\cdot}21}{2} = 1{\cdot}105 \times 60$ ft. $= 66{\cdot}3$ lbs. and $\frac{233{\cdot}1+66{\cdot}3}{18} = 16{\cdot}63$ lbs. per ton.

For tenth parts of a mile, multiply the number of tenth parts of a mile by one-tenth the difference between the mean resistance found as above, and the next mileage, or by one-tenth of the difference between the nearest mileages when they are given consecutively.

Taking the velocity 21·4 miles per hour and train 18 tons, as before, we have for the train 22 miles $\frac{13{\cdot}3-12{\cdot}95}{10}$ for 21 miles $\times 4 + 12{\cdot}95 = 13{\cdot}09$ lbs. $\times$ 18 tons $= 235{\cdot}62$ lbs., and for the atmosphere $\frac{1{\cdot}21-1{\cdot}105}{10} \times 4 + 1{\cdot}105 = 1{\cdot}147 \times 60 = 68{\cdot}82$ lbs.; and $\frac{235{\cdot}62+68{\cdot}82}{18} = 16{\cdot}9$ lbs. per ton.

TABLE III.

Table of the Indicator and Dynamometer Resistances to Railway Trains on the Broad Gauge, abstracted from the experiments of Mr. D. Gooch, as published in the Appendix to the Railway Commissioners' Report to the House of Lords shewing the Resistances, separately, of the Engine, Train, and Working Parts of the Engine; also the separate resistances as calculatod by the Formula.

1st Series of Experiments, made with a Train of 100 Tons, exclusive of Engine and Tender.														Theoretical Resistances for 100 Tons Trains.								
Resistance in lbs.					Velo-city.	Weight.			Resistance in lbs. per ton.			Velocity.	Remarks.	Resistances by formula in lbs.						In lbs. per ton.		
														of train only.								
Of train only by Dynamometer.	Of engine and train by Indicator.	Of engine and tender only.	Of engine and tender at the ratio of the train.	Of working parts of the engine.	In miles per hour.	Of engine and tender.	Of train.	Total.	Of train only by Dynamometer.	Of engine and train by Indicator.	Of engine and tender.	Variations of. (I.) Increased. (R.) Reduced.	State of the weather, &c.	Friction.	Atmo-spheric.	Oscilla'ion.	Total of train	Of engine and tender.	Total of engine and train.	Of train only.	Of engine and tender.	Of engine and train.
lbs.	lbs.	lbs.	lbs.	lbs.	Miles.	Tons.	Tons.	Tons.	lbs.	lbs.	lbs.	Miles.		lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
756	1363	607	383·3	223·7	13·1	50·7	100	150·7	7·56	9·04	11·97	R. 1·4	slight side.	600	61·7	87·3	749	620·	1369	7·49	12·23	9·08
843	1794	951	435·	516·	19·4	51·6	100	151·6	8·43	11·83	18·43	I. 1·6	slight.	600	135·4	128·	863	836·	1699	8·63	16·2	11·2
901	1623	722	457·7	264·3	19·8	50·8	100	150·8	9·01	10·76	14·21	I. 1·1	moderate side.	600	141·1	132·	873	836·	1709	8·73	16·45	11·33
909	1736	827	445·4	381·6	19·8	49·	100	149·	9·09	11·65	16·88	uniform.	strong side.	600	141·1	132·	873	806·5	1679	8·73	16·5	11·26
819	1845	1026	411·1	614·9	20·2	50·2	100	150·2	8·19	12·28	20·43	I. 1·7	moderate side.	600	146·8	134·6	881	839·8	1721	8·81	16·73	11·46
843	1650	807	428·2	378·8	21·1	50·8	100	150·8	8·43	10·94	15·88	uniform.	do. do.	600	160·2	140·6	900	880·	1780	9·	17·32	11·8
2110	3891	1781	1101·4	679·6	44·1	52·2	100	152·2	21·1	25·56	34·11	I. 3·5	strong side.	600	700·	294·	1594	1817·	3411	15·94	34·8	22·41
1436	3237	1801	692·1	1108·9	45·3	48·2	100	148·2	14·36	21·84	37·36	I. 1·8	do. do.	600	738·7	302·	1640	1728·3	3368	16·4	35·85	22·72
1850	3761	1911	925·	986·	45·6	50·	100	150·	18·50	25·07	38·22	uniform.	slight side.	600	748·5	304·	1652	1805·8	3458	16·52	36·11	23·05
2180	4649	2469	1072·5	1396·5	56·6	49·2	100	149·2	21·8	31·16	50·18	,,	strong side.	600	1153·	377·3	2130	2268·8	4399	21·3	46·11	29·48
1781	3556	1775	872·6	902·4	57·4	49·	100	149·	17·81	23·86	36·22	R. 1·4	do. do.	600	1186·	382·6	2168	2296·8	4465	21·68	46·85	29·96
2183	failed.				58·1	50·2	100	150·2	21·83	failed.		I. 1·6	do. do.	600	1215·	387·3	2202	2387·	4589	22·02	47·55	30·55
2438	,,				59·4	45·8	100	145·8	24·38	,,		I. 1·6	do. do.	600	1270·	396·	2264	2238·	4502	22·64	48 87	30·88
1980	,,				61·3	49·5	100	149·5	19·8	,,		uniform.	nearly calm.	600	1352·	408·6	2360	2508·5	4869	23·60	50·68	32·56

TABLE III.—*Continued.*

2nd Series of Experiments, made with a Train of 50 Tons, exclusive of Engine and Tender.														Theoretical Resistances for 50 Tons Trains.								
Resistance in lbs.					Velocity.	Weight.			Resistance in lbs. per ton.			Velocity.	Remarks.	Resistances by Formula in lbs.						In lbs. per ton.		
														of Train only.								
Of train only by Dynamometer.	Of engine and train by Indicator.	Of engine and tender only.	Of engine and tender at the ratio of the train.	Of working parts of the engine.	In miles per hour.	Of engine and tender.	Of train.	Total.	Of train only by Dynamometer.	Of engine and train by Indicator.	Of engine and tender.	Variations of. (I.) Increased. (R.) Reduced.	State of the weather, &c.	Friction.	Atmospheric.	Oscillation.	Total of train.	Of engine and tender.	Total of engine and train.	Of train only.	Of engine and tender.	Of engine and train.
lbs.	lbs.	lbs.	lbs.	lbs.	Miles.	Tons.	Tons.	Tons.	lbs.	lbs.	lbs.	Miles.		lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
443	1404	961	454·5	506·5	19·8	51·3	50	101·3	8·36	13·87	18·73	I. 1·1	slight side.	300	70·5	66·	436	804·5	1240	8·72	15·68	12·24
464	1437	973	450·	523·	21·8	48·5	50	98·5	9·28	14·58	20·06	partly unif^m.	moderate.	300	85·5	72·6	458	817·2	1275	9·16	16·85	12·94
521	1417	896	521·	375·	24·7	50·	50	100·	10·42	14·17	17·92	I. 1·3	strong side.	300	109·8	82·3	492	928·5	1420	9·84	18·57	14·20
1194	3162	1968	1234·5	733·5	40·1	51·7	50	101·7	23·88	31·09	38·06	I. 7·8	slipping.	300	289·4	133·6	723	1461·6	2184	14·46	28·27	21·48
690	1923	1233	684·5	548·5	42·3	49·6	50	99·6	13·8	19·3	24·86	uniform.	slight side.	300	322·	141·	763	1474·7	2237	15·26	29·73	22·46
724	2085	1361	716·7	644·3	43·9	49·5	50	99·5	14·48	20·95	27·49	,,	strong side.	300	346·8	146·3	793	1524·7	2317	15·86	30·8	23·29
786	1961	1175	798·5	376·5	44·	50·8	50	100·8	15·72	19·45	23·11	R. 3·	stormy, slipping.	300	348·4	146·6	795	1568·2	2363	15·9	30·87	23·44
854	2711	1857	855·7	1001·3	51·2	50·1	50	100·1	17·08	27·08	37·07	R. 4·	stormy ahead.	300	471·	170·6	942	1795·5	2737	18·82	35·84	27·33
1111	3196	2085	1126·5	958·5	58·	50·7	50	100·7	22·22	31·73	41·12	I. 1·4	slipping.	300	605·5	193·3	1098	2064·7	3162	21·96	40·72	31·4
1309	3278	1969	1314·2	654·8	59·2	50·2	50	100·2	26·18	32·71	39·22	I. 3·2	moderate side.	300	630·8	197·4	1128	2088·	3216	22·56	41·6	32·09
1539	3731	2192	1520·5	671·5	59·2	49·4	50	99·4	30·78	37·53	44·37	I. 3·2	strong side.	300	630·8	197·4	1128	2055·	3183	22·56	41·6	32·02
819	2374	1555	825·5	729·5	62·4	50·4	50	100·4	16·38	23·64	30·85	R. 7·	calm.	300	700·8	208·	1208	2216·6	3414	24·16	43·98	34·
3rd Series of Experiments, made with a train of 80 Tons, exclusive of Engine and Tender.														Theoretical Resistances for 80 Tons Trains.								
1036	cards not taken.				43·2	50·	80	130	12·95	cards not taken.		R. 4·6	up grad^t. $\frac{1}{352}$. allow^d. 6·3 lbs. per ton.	480	537·4	230·4	1247·8	1628·5	2876	15·59	32·57	22·12
836					47·	59·	80	130	10·45			R. 1·9		480	636·1	250·6	1366·7	1778·	3144	17·08	35·56	24·17
1772					48·5	50·	80	130	22·15			I. 3·7	calm.	480	677·4	258·6	1416·	1838·	3254	17·7	36·76	25·03
632					51·9	50·	80	130	7·9			R. 5·	mom^m. given out.	480	773·7	276·8	1530·5	1978·3	3509	19·13	39·56	26·99
1555					56·8	50·	80	130	19·4			I. 1·4	calm.	480	929·1	302·9	1712·0	2186·	3898	21·4	43·72	29·98

TABLE IV.

Table to facilitate the Calculation of Resistances to Broad-gauge Locomotive Engines of the class of the 'Great Britain' (weighing about 50 tons), and Trains, in lbs. per ton, and in lbs. per cubic foot of Bulk, on a calm day, on a level line in good order, with Engine, Tender, and Carriages, also in good working order, from 5 to 75 miles per hour: calculated from Formula, page 534, based on the Indicator and Dynamometer Traction of the Experiments made by Mr. D. Gooch, on the Bristol and Exeter Railway.

Velocity.	Resistance in lbs. per ton.						Velocity.	Resistance in lbs. per ton.					
	Friction and Oscillation.	Atmosphere per ton of 180 cubic feet of bulk.	Total resistance of the carriages per ton.	Engine and Tender. Per ton of their own weight.	Engine and Tender. Per ton of the weight of the train.	Atmosphere per cubic foot of bulk.		Friction and Oscillation.	Atmosphere per ton of 180 cubic feet of bulk.	Total resistance of the carriages per ton.	Engine and Tender. Per ton of their own weight.	Engine and Tender. Per ton of the weight of the train.	Atmosphere per cubic foot of bulk.
Miles.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	Miles.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
5	6·33	·090	6·42	7·5	·001	·0005	41	8·73	6·05	14·78	25·5	·0672	·03362
6	6·4	·129	6·539	8·	·0014	·00072	42	8·8	6·35	15·15	26·	·0705	·03528
7	6·46	·176	6·636	8·5	·0019	·00097	43	8·86	6·65	15·51	26·5	·0739	·03699
8	6·53	·230	6·76	9·	·0025	·00128	44	8·93	6·97	15·89	27·	·0774	·03872
9	6·6	·291	6·891	9·5	·0032	·00162	45	9·	7·29	16·39	27·5	·081	·0405
10	6·66	·36	7·02	10·	·004	·002	46	9·06	7·61	16·67	28·	·0846	·04232
11	6·73	·435	7·165	10·5	·0048	·00242	47	9·13	7·95	17·08	28·5	·0883	·04418
12	6·8	·518	7·318	11·	·0057	·00288	48	9·2	8·29	17·49	29·	·0921	·04608
13	6·86	·608	7·468	11·5	·0067	·00338	49	9·26	8·64	17·90	29·5	·096	·04802
14	6·93	·705	7·635	12·	·0078	·00392	50	9·33	9·	18·33	30·	·10	·05
15	7·	·81	7·81	12·5	·009	·0045	51	9·4	9·36	18·76	30·5	·104	·05202
16	7·06	·921	7·981	13·	·0102	·00512	52	9·46	9·73	19·19	31·	·1081	·05408
17	7·13	1·04	8·13	13·5	·0115	·00578	53	9·53	10·11	19·64	31·5	·1123	·05618
18	7·2	1·166	8·366	14·	·0129	·00648	54	9·6	10·49	20·09	32·	·116	·05832
19	7·26	1·299	8·559	14·5	·0144	·00722	55	9·66	10·89	20·55	32·5	·121	·0605
20	7·33	1·44	8·77	15·	·016	·008	56	9·73	11·29	21·02	33·	·1254	·06272
21	7·4	1·587	8·987	15·5	·0176	·00882	57	9·8	11·69	21·49	33·5	·1299	·06498
22	7·46	1·742	9·202	16·	·0193	·00968	58	9·86	12·11	21·97	34·	·1345	·06728
23	7·53	1·904	9·454	16·5	·0211	·01058	59	9·93	12·53	22·46	34·5	·1392	·06962
24	7·6	2·073	9·673	17·	·023	·01152	60	10·	12·96	22·96	35·	·144	·072
25	7·66	2·25	9·885	17·5	·025	·01252	61	10·06	13·39	23·45	35·5	·1488	·07442
26	7·73	2·43	10·16	18·	·026	·01352	62	10·13	13·83	23·96	36·	·1537	·07688
27	7·8	2·62	10·42	18·5	·0291	·01458	63	10·2	14·29	24·49	36·5	·1587	·07938
28	7·86	2·82	10·68	19·	·0313	·01568	64	10·26	14·74	25·00	37·	·1638	·08192
29	7·93	3·027	10·957	19·5	·0336	·01682	65	10·33	15·21	25·54	37·5	·169	·0845
30	8·	3·24	11·24	20·	·036	·018	66	10·4	15·68	26·08	38·	·1742	·08712
31	8·06	3·459	11·51	20·5	·0384	·01922	67	10·46	16·16	26·62	38·5	·1795	·08978
32	8·13	3·68	11·81	21·	·0409	·02048	68	10·53	16·46	27·01	39·	·1849	·09248
33	8·2	3·92	12·12	21·5	·0435	·02178	69	10·6	17·14	27·74	39·5	·1904	·09522
34	8·26	4·16	12·42	22·	·0462	·02312	70	10·66	17·64	28·30	40·	·196	·098
35	8·33	4·41	12·74	22·5	·049	·0245	71	10·73	18·14	28·87	40·5	·2016	·10082
36	8·4	4·66	13·06	23·	·0518	·02592	72	10·8	18·66	29·46	41·	·2073	·10368
37	8·46	4·92	13·38	23·5	·0547	·02738	73	10·86	19·18	30·04	41·5	·2131	·10658
38	8·53	5·19	13·72	24·	·0577	·02888	74	10·93	19·71	30·64	42·	·219	·10952
39	8·6	5·47	14·07	24·5	·0608	·03042	75	11·	20·25	31·25	42·5	·225	·1125
40	8·66	5·76	14·42	25·	·064	·0320							

Note.—For miles and tenth parts of a mile, the resistance is found by multiplying the number of tenths by one-tenth the difference between the two nearest mileages, and adding it to the resistance for the whole number.

Thus for the train resistance for 61·3 miles per hour, take for 62 miles 23·96 − 23·45 for 61 miles an hour $= \frac{\cdot 51}{10} \times \cdot 3 + 23{\cdot}45 = 23{\cdot}60$ lbs. per ton; and in like manner for any other resistance.

TABLE V.

Table of Gradients, and Resistance per ton for each Gradient.

Vertical Rise.		Gravity due to incline per ton.	Vertical Rise.		Gravity due to incline per ton.	Vertical Rise.		Gravity due to incline per ton.
Ratio	per mile.		Ratio	per mile.		Ratio	per mile.	
One in	Feet.	lbs.	One in	Feet.	lbs.	One in	Feet.	lbs.
100	52·80	22·40	74	71·38	30·270	47	112·34	47·660
99	53·33	22·626	73	72·32	30·685	46	115·04	48·684
98	53·88	22·858	72	73·33	31·111	45	117·33	49·777
97	54·43	23·092	71	74·36	31·550	44	120·0	50·908
96	55·00	23·334	70	75·43	32·000	43	122·78	52·092
95	55·60	23·579	69	76·49	32·464	42	125·71	53·333
94	56·17	23·830	68	77·64	32·940	41	128·78	54·634
93	56·77	24·086	67	78·81	33·432	40	132·00	56·00
92	57·52	24·342	66	80·0	33·940	39	135·38	57·436
91	58·02	24·614	65	81·23	34·460	38	138·95	58·944
90	58·66	24·888	64	82·50	35·0	37	142·70	60·540
89	59·33	25·168	63	83·81	35·555	36	146·66	62·222
88	60·0	25·454	62	85·16	36·108	35	150·84	64·000
87	60·69	25·746	61	86·55	36·720	34	155·30	65·880
86	61·39	26·046	60	88·00	37·333	33	160·0	67·880
85·16	62·00	26·303	59	89·49	37·966	32	165·0	70·0
85	62·12	26·353	58	91·03	38·620	31	170·32	72·216
84	62·86	26·666	57	92·63	39·298	30	176·00	74·666
83	63·61	26·988	56	94·28	40·0	29	182·06	77·240
82	64·39	27·317	55	96·00	40·726	28	188·56	80·00
81	65·20	27·718	54	97·77	41·480	27	195·55	82·960
80	66·0	28·00	53	99·62	42·264	26	203·06	86·152
79	66·83	28·355	52	101·53	43·076	25	211·20	89·60
78	67·69	28·718	51	103·52	43·920	24	220·0	93·336
77	68·57	29·090	50	105·60	44·800	23	229·56	97·368
76	69·47	29·472	49	107·75	45·716	22	240·0	101·816
75	70·40	29·867	48	110·00	46·688	21	251·43	106·666

TABLE VI.

Table of the Number of Revolutions of the Driving Wheels, or double Strokes of th Piston, per minute, at the following given Speeds.

Revolutions of Wheels, or double Strokes of the Piston, per Minute.									Miles per hour.
DIAMETERS OF DRIVING WHEELS.									
4 ft.	4½ ft.	5 ft.	5½ ft.	6 ft.	6½ ft.	7 ft.	7½ ft.	8 ft.	
No.	No.	No.	No.	No.	No.	No.	No.	No.	No.
210·18	189·54	168·18	152·85	140·04	129·30	120	112·02	105	30
245·21	221·13	196·21	177·29	163·33	150·85	140	130·69	122·5	35
280·24	252·72	224·24	203·76	186·72	172·40	160	149·36	140·0	40
315·27	284·30	252·27	229·23	210·06	193·95	180	168·03	157·5	45
350·30	315·90	280·30	254·75	233·40	215·50	200	186·70	175·0	50
385·33	347·49	308·33	280·17	256·74	237·05	220	205·37	192·5	55
420·36	379·08	336·36	305·64	280·5	258·6	240	224·04	210·1	60
455·39	416·67	364·39	331·11	303·42	280·15	260	242·71	227·5	65
490·42	442·19	392·42	356·58	326·76	301·70	280	261·38	245	70
525·45	473·85	420·50	372·05	350·10	323·25	300	280·05	262·5	75
560·48	505·50	448·48	407·60	373·44	344·80	320	298·72	280	80

TABLE VII.

Table of the Results of various Experiments, shewing the resistance to Trains of different Weights and different Velocities, in all cases where such velocities have been uniformly maintained in calm weather, on Lines of uniform inclination, and free from sharp curves; the road and carriages being in good working order. The resistances are measured either by the effect of gravity on inclined planes, or by the difference of pressure on the travelling piston of the Atmospheric Railway apparatus, except in two cases marked with a †, in which the resistance is indicated approximately by the effect theoretically due to steam generated and made use of under known conditions in a Locomotive Engine.

No. of carriages	Uniform velocity maintained in miles per hour.	Weight.	Resistance in lbs. per ton.	Resistance in lbs. per ton, as Formula.	Wind.	No. of carriages.	Uniform velocity maintained in miles per hour.	Weight.	Resistance in lbs. per ton.	Resistance in lbs. per ton, as Formula.	Wind.
No.	Miles.	Tons.	lbs.	lbs.		No.	Miles.	Tons.	lbs.	lbs.	
2	14	9·	12·6	13·9	Favble.	6	34	30·4	25·0	23·1	Nearly calm.
2	14	9·	12·6	13·9	,,	4	34	18·05	23·4	27·2	Favourable.
4	16	20·5	8·5	13·2	,,	6	35	21·5	22·5	26·1	Calm.
8	19	40·75	8·5	12·9	,,	E. T. & 9	36	64·	22·5	22·4	,,
8	20	40·75	8·5	14·1	,,	4	37	20·4	25·0	28·4	Favourable.
4	21	18·	12·6	16·7	,,	3	39	24·0	30·0	31·0	,, B.
4	21	18·	12·6	16·7	,,	E. T. & 13	45	111·	30·3	24·9	Nearly calm.†
4	23	20·5	12·6	17·5	,,	E. T. & 3	46	54·	30·	27·5	Light, fav. B.
8	25	40·75	12·6	16·6	,,	3	47	31·75	33·7	33·1	Light, against.
8	26	40·75	12·6	17·1*	,,	6	50	30·	32·9	35·3	Calm.
8	27	40·75	12·6	17·7	,,	5	53	25·	41·7	42·1	,,
4	31	15·6	23·4	25·4	,,	5	55	26·	36·	43·5	Light, against.
4	32	14·5	22·5	27·2	Calm.	E. T. & 6	55	93·	41·3	31·6	Calm. † B.
E. T. & 6	33	44·	22·5	22·7	,,	4	61	21·5	52·6	54·8	,,

Note.—E. T. signifies that these experiments were made with an engine and tender in front. All the others were made with carriages only.

* Space between carriages made up with stretched canvas. B. Experiments on broad gauge.

TABLE VIII.

Table shewing the Resistance caused by the Blast Pipe in lbs. *and per cent. of the Total Pressure on the Piston at various Pressures and Velocities, as taken from the cylinder of the 'Great Britain' (broad-gauge) locomotive engine, by Indicator, during the Experiments made by Mr. D. Gooch for the Railway Commissioners. (See Table III.) Also the Back Pressure, calculated by the Formula* $P^2 + V \times R \times {\cdot}00001$, *page* 526. *Driving wheels* 8 *feet diameter, cylinder* 18 *inches diameter and* 24 *inches stroke. Orifice of blast pipe* 5 *inches diameter. Steam ports* $13 \times 2 = 26$ *inches. Lead of slide valves* $\frac{1}{4}$ *inch fall, fitted up with expansion gear. Exhaust port* $13 \times 3\frac{1}{2} = 45\frac{1}{2}$ *inches.*

Experiments with Engine and Tender 50 Tons, Train 100 Tons = 150 Tons.				
	From Indicator Cards.			By Formula.
Velocity per hour.	Mean pressure on steam side of the piston.	Mean pressure on blast-pipe side of the piston.	Ratio per cent. of back pressure to total pressure on the piston.	Back pressure by formula.
Miles.	lbs.	lbs.	Per cent.	lbs.
13·1	19·1	2·27	11·88	1·7
19·4	25·7	1·9	7·39	2·89
	24·95	2·38	9·53	2·78
	23·91	2·45	10·24	2·62
	22·87	2·06	9·	2·46
19·8	19·75	1·91	9·67	2·07
	25·39	2·06	8·11	2·86
	24·27	1·54	6·34	2·69
	24·33	2·29	9·41	2·70
19·8	24·58	4·33	17·63	2·74
	24·33	4·5	18·5	2·70
20·2	11·7	2·29*	19·57	1·30
	25·29	1·79	7·07	2·88
	24·	1·95	8·12	2·67
21·1	23·95	2·05	8·56	2·70
	23·85	2·39	10·	2·68
	21·43	2·0	9·33	2·34
	20·83	2·13	10·22	2·26
44·1	57·72	10·3	17·84	12·28
	58·	10·87	18·74	12·88
	59·	10·72	18·17	12·74
	60·2	19·82	17·97	13·18
45·3	55·16	15·20	27·59	11·43
	47·66	24·37*	51·13	9·03
45·6	58·85	11·37	19·32	12·75
	57·27	11·87	20·72	12·18
	34·77	5·87*	16·88	5·74
56·6	79·4	22·5	28·33	22·08
	80·6	21·9	27·17	22·66
	81·1	21·6	26·63	22·92
	77·52	23·	29·67	21·15
57·4	60·87	14·81	24·33	14·02
	57·93	14·45	24·94	12·93
	58·09	12·47	21·47	13·
	54·95	14·54	26·46	11·89

Experiments with Engine and Tender 50 Tons, Train 50 Tons = 100 Tons.				
	From Indicator Cards.			By Formula.
Velocity per hour.	Mean pressure on steam side of the piston.	Mean pressure on blast-pipe side of the piston.	Ratio per cent. of back pressure to total pressure on the piston.	Back pressure by formula.
Miles.	lbs.	lbs.	Per cent.	lbs.
19·8	19·31	1·31	6·78	2·02
	18·85	1·52	8·06	1·96
	18·52	1·85	9·98	1·92
21·8	30·2	3·79	12·55	3·78
	26·75	3·75	14·02	3·17
	22·87	3·91	17·09	2·57
	20·5	3·95	19·27	2·25
24·7	19·37	1·58	8·15	2·24
	18·	1·5	8·33	2·08
	19·7	1·5	7·61	2·27
	19·06	1·55	8·13	2·20
40·1	44·91	6·58	14·63	8·02
	47·08	7·79	16·54	8·61
	46·87	7·62	16·25	8·57
42·3	30·79	6·95	22·57	4·79
43·9	30·27	4·63	15·3	4·76
	31·83	5·05	15·86	5·06
	29·62	4·33	14·61	4·64
44·	34·18	5·61	16·41	5·55
	27·41	5·37	19·59	4·52
	28·25	5·14	18·19	4·39
51·2	43·19	9·71	22·48	8·03
58·	49·6	11·56	23·3	10·17
	52·22	12·29	23·53	11·
59·2	58·85	18·37	31·21	13·34
	59·41	14·74	24·81	13·53
	63·14	17·18	27·2	14·97
	66·20	18·7	28·25	16·2
	65·08	18·95	29·11	15·75
62·4	40·62	11·45	28·18	7·84
	37·68	8·87	23·54	7·32
	38·62	8·52	22·06	7·35

* Priming or slipping when card was taken.

Note.—A more condensed Table of the mean resistances for each velocity would have given fair averages with fewer variations than by giving them all separately. As, however, they were taken under all the changing circumstances from calm to stormy weather—from velocities of 13 to 62 miles an hour—slipping—when priming was observed, and probably also when it was with other contingencies not observed, they form a valuable record of the practical variations taking place in a locomotive cylinder. It will be observed that, as a whole, they follow nearly the general law of the formula.

SECTION III.—QUALIFICATIONS OF ENGINE DRIVERS AND FIRE-MEN.*

Tickets.—Each engine-man, before going out with his train, must procure from his foreman's office a train and coke and mileage ticket, to be filled up by him in the following manner: First, the exact time at which the train is started; second, the number and description of the carriages in the train; and upon arriving at the end of his trip, he must enter the time of his arrival, with any remarks he may have to make upon his trip, such as being assisted by another engine, how far assisted, and, if late, the cause of the delay.

On the coke and mileage ticket he must enter the number of trips he runs, the names of the stations between which they are run, and the number of miles; also the time his engine stands as a pilot. On this ticket must also be entered the weight of coke he receives during the day, attested by the signature of the coke-man where it is received; the engine-man, in turn, signing the coke-man's book for the quantity he received. Great attention should be given that these tickets are properly filled up, as they exhibit very accurately the performances of the engines, when carefully made up by each engine-man. Neglect of proper entries should be punished by a small fine.

Time bill.—Every engine-man must take his time-table with him, and regulate by it the speed of his engine as he proceeds; the great object being to keep the train going at the speed required, from which he should vary as little as possible, in order that he may arrive at all the stations as punctually to the time as is practicable.

Whistles, when to be used.—The whistle is intended to be used as a signal of attention or of danger, and it must be sounded on approaching stations, level crossings, and tunnels; also, during a fog, snow-storm, or violent rain, it must be sounded every quarter of a mile, and likewise for warning any persons who may be on the line of the approaching engine and train. On lines where only one whistle is used, three short, sharp whistles, rapidly repeated, is the signal for danger; on other lines, a better description of guard's whistle is used, with a deep tone. When either of these signals is made, the guard must immediately apply his brakes, and do all he can to stop the train.

Water and coke.—The engine-man must take his engine to the water-crane, have his tender filled with water, and receive as much coke as will carry him to the next watering and coking station. He must not pass one of these stations without renewing his supply of both coke and water, if he requires it. When steam is blowing off, the hot-water cock should be turned on to heat the water in the tender, and he must have a full boiler, and a good fire, before he goes to the train.

Lamps.—Before dark, or in the evening before it is dusk, or in a fog, the engine-man must see that his lamps are lighted and properly fixed in their places; and if he should have to go out without a train, then he must fix a red lamp behind the tender. Should he be on the line, through any unforeseen cause, without his lamps, he must procure some from the first principal station he comes to.

Going to train.—The engine-man having assured himself, by a careful examination, that his engine, lamps, tools, and spare stores are all in good order, and obtained his train, coke, mileage and time tickets, must cross over to the main line, in front of the train, five minutes before the time of starting, unless ordered otherwise by some superior officer.

Great caution must be used in placing the engine against the train, which should be done without moving a single carriage, in order to guard against injury to any passenger who may be in the act of stepping into a carriage at that moment.

Guards' orders.—Every engine-man will be under the orders of the first guard of

* By John Sewell, C.E.

the train in all matters affecting the starting, stopping, or the movements of the train. In cases of accident, he must, if required, disconnect his engine, and proceed for assistance as he may be instructed by the first guard. He must also give both his advice and assistance to the guard in every way he can in all cases of accident, and generally obey promptly all orders or signals given to him, whether by station masters or the first guards, so far as the safe and proper working of his engine will admit.

Engine standing.—While the engine is standing still, whether before starting, or at a station, or on the line, for however short a time, the slides must always be thrown out of gear, the steam shut off, and the tender-brake screwed tight on, until the signal be given for starting. The engine-man must be very careful to start, and stop, steadily, without jerking the train, and not shut off the steam too suddenly (unless in cases of accident), so as to cause a concussion of the carriages, or waggons, to the risk of passengers, and, in cattle trains, to the injury of the animals. He must at no time leave his engine without seeing the above rules strictly complied with, and then not without placing the engine in charge of his fire-man.

Persons on tender.—Except the proper engine-man and fire-man, no person is allowed on the engine or tender without the permission of the Directors or one of the superior officers of the Company, or, in case of need, during the journey, by direction of the first guard of the train.

Starting the train.—Every engine-man, on receiving the signal from the first guard to start the train, must sound his whistle BEFORE TURNING ON THE STEAM; then place himself by his hand gear, and very carefully and gradually open the regulator, to prevent jerking of the carriages, slipping, priming, or other injury to his engine. When the engine has got into speed, he must then regulate the travel of his slides, according to the load, and open the regulator to that point, determined by experience, where the generation and consumption of steam take place with greater effect and economy than when the regulator is full open. Nothing should induce the engine-man to use steam of a higher pressure than is allowed by the locomotive superintendent.

Water in the cylinders.—The condensed steam in the cylinders must be allowed to escape by the steady and gradual opening of the regulator and likewise of the cylinder cock, as the sudden opening of the regulator is liable to break the piston or cylinder-cover joints, when there is water in the cylinders.

Priming.—When priming takes place from the boiler, the steam must be partly shut off, and the fire door opened, which will generally stop it. But if it arises from the boiler being too full, the feeds must be shut off, to reduce the water to its proper level. When the boiler is not too full, the feeds must not be shut off, in order to save the tubes and fire-box, which would thus become exposed from the rapid waste of water by the priming, if such waste was not kept up by the feeds.

Slipping.—When an engine begins to slip, the steam must be nearly all shut off, and carefully regulated until slipping ceases. Engines should have two sand-boxes, which should then be opened, that equal bite may be given to both driving wheels from the sand dropping on the rails. When the slipping ceases, the slides of the sand-boxes must be shut off, and the regulator gradually opened to its proper place. A third sand-box is used for backing a train with.

Feeding water.—The supply of water to the boiler must be carefully regulated so as to keep both feeds on at an uniform rate all the way, thereby keeping the boiler at a proper and equal level, for the more rapid and regular generation of steam. When near the end of a trip, the feeds may be gradually increased as shall be required to fill up the boiler, before arriving at the station. The feeds should at no time be too suddenly opened, as doing so is very liable to break the clacks.

Firing.—Coke must, as far as possible, be put on the fire at such places as do not

require the full power of the engine. The steam must be partly shut off when coke is put on the fire, as, when the steam is full on, the strong draft carries the coke up against the tubes, and is liable to choke them up. When approaching the end of the trip, the small coke must be used, and the fire allowed to burn as low as will take the train on to the station safely.

Attention to Signals.—Every engine-man must keep a good look-out, as he moves forward, for any signals, either from the police or from any other person, or for any indication of danger made to him, or which he may observe himself,—all which he is responsible for seeing and immediately attending to; and he must obey any signal made by a policeman, or gatekeeper, even if he should see reason to think such signal unnecessary. The lives of the passengers are intrusted to his care, and it is fully expected that he shall not only attend to every signal given him, and to all his instructions, but also that he will, on all occasions, be vigilant and cautious himself, not trusting entirely to signals for safety. (*See* article 'Railway.')

Hand-flags in windy weather are a very bad signal, painted boards being much better, as they always shew their full size, whilst the wind not unfrequently makes the hand-flag appear a mere line.

Waving a white light violently is also a signal of danger, when a red light is not to be had. Fog, night, and tunnel signals are made by lamps and detonators; day signals by policemen, hand-flags, painted boards, and high-mast signals. As signals vary on different lines, each engine-man is supplied with a set of the Rules and Regulations of the Company he is employed by, describing the particular signals used, and which must be strictly attended to on every occasion.

Fire-men's duties.—Fire-men are to be entirely under the orders of the engine-men while on duty. If the engine-man is engaged with any part of the engine, the fire-man must keep on the look-out, and act for the engine-man, and they must never both leave the engine at the same time. The fire-man must at all times stand up and keep a good look-out, when not otherwise engaged in attending to his other duties; and he must, each mile, look back along both sides of the train, to see that all is right, and that the guards are not signalling by hand or lamp to the engine-man. When the fire-man is so engaged that he cannot look back, he must warn the engine-man, who will then do so himself. The fire-man must also be ready, at all times, at a signal from the engine-man, to go to the brake, and, when approaching any station where the engine is to stop, or observing any obstruction on the line, or seeing any signal intimating danger or caution, it is the duty of the fire-man, without waiting for orders, to go to the brake, and to warn the engine-man instantly. Should the engine-man be rendered incapable of doing his duty, whether by accident or otherwise, the fire-man is to take the management of the engine until another driver can be obtained, proceeding with caution, and reporting the circumstance to the first guard at the earliest opportunity.

Guards' signals.—Guards should regularly signal to the engine-man that all is right; but if anything is wrong, they must give the caution or danger signal. The usual signal from the engine-man to the guards is by three short sharp whistles on some lines; on others, by a deep-toned guard's whistle,—an excellent plan, preventing the liability of any mistake whatever in the use of the whistles. On this signal being given, the guard must instantly signal that it is understood, to the fire-man, who must look back immediately the signal is given by the engine-man, to observe which signal the guard gives. This signal and answer must be made within the first half mile after starting with a goods train, and every two miles afterwards by the guards on the journey. With passenger trains, this signal must be made every mile on the journey ; the whistle being used only in cases of need.

Engine-men's signals.—Engine-men must also signal one another when on the road, by standing on the right-hand side of the engine, so as to be next each other in passing, and must always do so with the same signals as those used on the line, to indicate whether the line they have passed is clear, or whether there is a train ahead, or any other cause of danger existing.

All trains to be drawn.—No engine must pass along the wrong line of road, nor be allowed to propel a train of carriages or waggons; but in all cases it must draw the train after it on the right road, except in case of an engine being disabled on the road, when the succeeding engine may propel the train slowly as far as the first 'shunt' or siding, at which place the said propelling engine shall move past and take the lead. In case of the road becoming stopped, when it will be unavoidably necessary for an engine to go back on the wrong line, the engine-man must send his fireman, or some other competent person, back a distance of not less than half a mile before his engine moves, to warn any engine coming in the opposite direction; and the person so sent back must continue to preserve the distance of half a mile between him and the engine, until it gets into the right line again.

Distance between engines.—All engines travelling on the same line must be kept at least two miles apart, unless expressly required to join on to the preceding train or engine, which the engine-man shall approach with the utmost caution. Such a step can only be justifiable under a pressing necessity.

Two engines working together.—When two engines are working together, the second engine-man must watch for and take his signals from the leading engine-man; but should the second engine-man discover anything wrong with the train, he must blow his whistle to warn the first engine-man, that the two engines may always check and stop together. Engine-men with trains requiring assistance, must in all cases, with passenger trains, allow the assistant engine to go in front, and also with goods trains, where practicable.

Part of train detached.—When any part of a train is detached, while in motion, care must be taken not to stop the engine or train in front before the detached part is stopped, no matter whether it has become detached intentionally or by accident, to prevent a dangerous collision with the carriages in front, should the latter stop first. Whenever an engine-man finds his engine disconnected from the train by accident or otherwise, he must keep his engine ahead, clear of the train altogether, and in no case pull up his engine until the train has been stopped by the aid of the guards' brakes, when he can move backwards, and couple on to the train in the usual way.

It is the duty of the guard of any intentionally detached part of the train to apply the brake so as to stop at the proper place.

Passing stations.—Every engine-man must be careful when he passes a station, or when the road is under repair, to proceed slowly and cautiously; and he must also do so whenever he sees a *green signal.* He must on no account pass a *red signal,* or any other which he understands to be a signal to stop, but bring his engine to a stand close to that signal.

Stopping at the proper station.—No engine or train of any sort must stop at any but the appointed stations, except only when a signal is given; or in case of accident to any part of the engine or train; or when, in the judgment of the engine-man, it is necessary to prevent accident or collision.

Caution in stopping trains.—Engine-men, in bringing up their trains, must pay particular attention to the state of the weather, the condition of the rails, the length of the train, and whether on a level, an ascending or descending incline, in determining when to shut off the steam, so as to reduce the speed in proper time, and enable them to have the train so completely under their command as to stop altogether, if

necessary, before reaching the platform. Stations must not be entered so rapidly as to require a violent application of the brakes, and the use of the carriage brakes must be avoided as much as possible.

Running on main line.—No engine must ever be moved from any of the stations on to the main line, except when the engine-man is proceeding, at the proper time, to take his place in front of the train. When on the main line, he must never run beyond the limits fixed at each station, without a regular order, filled up and signed by the proper foreman; and he must strictly follow the instructions contained in such order, both as regards the time of starting and the place and time of returning.

Standing on main line.—No engine must be allowed to stand on the main line (except under very special circumstances) when not attached to a train; and no engine-man must leave his engine or train, or any part thereof, on the main line, unless there be a competent person in charge to make the necessary signals: neither must any engine cross the line of railway at a station without permission, or run tender foremost, without the orders of the locomotive superintendent, or from unavoidable necessity.

EXTRA TRAINS.

Signal for extra train.—Whenever a red board, or flag, by day, or an extra red lamp by night, is carried on the last carriage or waggon of a train, it is an indication that a special or extra train is to follow, that the road and stations may be kept clear for it.

On single line.—To avoid risk of collision on single lines, from the meeting of another engine, no extra engine, with or without a train, must be allowed to pass along the line without previous notice.

LUGGAGE TRAINS.

Approaching stations.—Engine-men with luggage trains must approach all stopping places at a speed not exceeding 12 to 15 miles an hour when within a quarter of a mile of the stopping-place; and, when necessary, they must signal the guards or brakes-men before they apply the tender brakes.

Uncovered waggons.—Engine-men must refuse to take up luggage waggons if they contain any goods of a nature to take fire from a spark falling amongst them, unless they are properly covered and tied down.

Goods trains into sidings.—Engine-men of luggage trains must not pass any siding or crossing when there is a passenger train coming in the same direction, due within fifteen minutes, but must remove from the main line to the siding; and generally all luggage, coal, and ballast trains must give way to passenger trains by going into the nearest sidings.

REPAIRING ROAD.

Ballasting.—When any ballast train shall stop on the main line to load or unload ballast or other materials, the engine-man must send a ballast-man back, at least a mile, with a red signal flag, or board, by day, or a red lamp by night; and the man must stand there, on the look-out, until the ballast train has moved off ten minutes, and stop any coming engine or train, and inform them of the position of the ballast train. No ballasting permitted in foggy weather, unless by a special order, or under the most urgent circumstances.

Caution for repairs.—When repairs of the road are going forward, and persons employed on the permanent way have the use of the road, a signal of danger may be given by those persons, either by a red flag or a red lamp; and on observing this signal the engine-man must immediately stop the train.

Train of empties.—Engines running alone, or with a train of empty carriages or

waggons, must not exceed a speed of 25 miles an hour without special orders in each case, or from urgent necessity.

ACCIDENTS.

Stoppages.—In case of any accident to the engine or train, causing a complete stoppage, the engine-man, after giving such directions to his fire-man to open the fire door, rake out the fire, or otherwise, as may be necessary for the safety of the engine, must immediately seek the first guard of the train, and communicate with him, and receive his directions; and in the absence of the first guard, the engine-man must himself ascertain whether the engine and train are clear of the opposite line, and of any train passing upon it, and, if they do not appear quite clear, remove the passengers from the carriages. He must also send back a guard or his fire-man, or a special messenger, to the next policeman, to stop any trains coming up. If dusk or dark, he must see that the carriage lamps in front, and his engine lamp, all show red lights forward, and the tail lamps, as usual, shew a red light backwards.

Hand pump.—Whenever, through any accident, an engine has to stand with steam up, the hand pump must be worked, to keep up the water in the boiler, the fire door opened, the damper shut, and other means used to prevent, as far as practicable, the generation of steam.

Detonating signals.—Every engine-man should be supplied with detonating signals, which he is responsible to have always ready for use when on duty. When a stoppage occurs in foggy weather, or at night, one of these signals must be placed on the rails, every 200 yards, until the guard, fire-man, or messenger has gone back a mile at least; and at the end of that distance, two of them must be placed on the rails. When any such accident happens in a tunnel, the engine-man should, if required, occasionally hold down the steam valve, to prevent the noise, and allow orders to be given and heard more readily. If dark, and without a red lamp or detonating signals, the man sent back must make a signal by waving his light up and down violently. If by day, he must signal with the red flag, or board, or hands, and must in all cases remain until relieved by a policeman, or the obstruction has been removed.

Both lines stopped.—Should the accident stop both lines of rails, then the same precautions must be taken to place the signals on the opposite line of rail to that which the train is on, but in a contrary direction, so that both lines of rails may be protected for at least a mile from the place of obstruction.

Train on fire.—Should fire be discovered in the train, the steam must instantly be shut off, and the train brought to a stand. The signals of obstruction or stoppage must then be made to protect the train, and the burning waggon, or whatever it may be, detached with as little delay as possible. Every means must then be used by the guards and engine-man to put out the fire by water from the tender, or by other means, as the necessity of the case may require. No attempt must be made to reach the nearest water crane, if it is more than 800 yards from the place where the fire is discovered, as such a course is likely to increase the damage.

Burst tube.—If a tube bursts badly, the steam and feeds must both be shut off, and the engine stopped as quickly as possible. A tube plug must then be driven into each end of it, and the boiler filled by the hand pump. As soon as water is seen in the glass, the fire can be got up again, and the hot fire-box will assist in doing so more quickly. As soon as the steam is up, the engine will be enabled to move on again. In most cases it will not be necessary to stop the engine, as the fire-box end can be plugged up when running, and the other end can be plugged at the first stopping station, without delaying the train.

Road obscured.—When the road is obscured by steam (from a burst tube or any

other cause), no approaching engine must pass through the steam or smoke until the engine-man has ascertained that the road is clear. If any engine-man sees a train stopped or stopping from accident, or other cause, on the opposite line of railway, he must immediately slacken his speed, so that he may pass such train slowly, and stop altogether, if necessary. He must then ascertain the cause of the stoppage, and report it to the next station. He must also, if necessary, stop all the trains between the spot and the next station, and caution the engine-men of the stoppage. He must also render every assistance in his power in all cases of necessity and of difficulty.

Broken clacks.—Should a pump or feed-pipe give way, one pump is generally sufficient to keep up the boiler; but should that one fail also, the engine must be stopped, and the clacks examined. The engine-man will know by his pet-cocks whether it is a top, middle, or bottom clack that is faulty. If a bottom or middle clack, the nut must be unscrewed, the broken clack taken out, one of his spare clacks put in, and the nut screwed on, when he will be ready to start his engine again. If it is the top clack, it can only be repaired when the steam is up; but unless the middle clack is also bad, the pumps will still work to keep up the water in the boiler.

Broken spring.—When a spring breaks, it will seldom be necessary to stop the engine until it reaches a station, when the side can be raised by moving the other wheels of the engine on to the two wedge-shaped bars, to be laid flat on the rails, which takes the weight off the wheel where the broken spring is, and allows it to be blocked up by one of the wooden wedges; the engine can then be moved off the bars and proceed with the train. The same operation may be done by the screw-jack, but the first causes least labour.

Broken machinery.—A railway locomotive is made up of two complete engines working separately, but both attached to a double crank-axle; therefore, whenever a cylinder-cover, piston, connecting rod, eccentric rod, quadrant, slides, or any other working part of the engines gives way on the road, which stops the working of one engine, the engine-man must immediately stop, and remove the broken parts or rods, so as to leave the other engine clear of all obstruction. He must then disconnect the slide of the broken engine, and adjust it so as to cover both the steam ports, where he must secure it by tying, if he has no other resource at hand. The best way of fixing the slide is by a set-bolt, fitted into the outside of the slide-rod guide, being screwed tight up against the slide-rod. A set-pin can also be used when a syphon cup is screwed on the guide, by taking off the syphon and introducing a screw of the same thread. When this is done, the engine will be able to proceed, working one cylinder only. Should the boiler have been pierced by any of the broken rods, the fire must be immediately drawn, to save the fire-box and tubes, and a competent person sent for the requisite assistance to remove the engine and train.

Working with one engine.—Whenever the engine-man has only one engine in working order, he will still be enabled to proceed with a light or ordinary train to the first pilot station, where the pilot engine will proceed with the train. Should the train be too heavy, he must consult the first guard whether to proceed with part of it, or not, for assistance, and be guided by his instructions.

Broken slide.—When the slide or slide-rod breaks within the steam chest, the engine must be stopped. If the slide is on the front side of the steam ports, and the exhaust port open, it should be pushed back through the front slide-rod gland, so far as to cover the ports. When there is no front slide-rod, but a set-bolt in the steam-chest cover, by taking out the bolt, the slide can be moved through that hole also; and if the slide is on the back, and the exhaust port open from the front of the slide,

it should be pushed forward through the slide-rod gland until it covers both ports. When impracticable to cover all the ports, from a bad regulator or other cause, or keep the slide over the ports, the connecting rod must be taken off, and the piston blocked, to prevent its moving by the pressure of the steam against it; when the engine-man can proceed with one engine, as before.

Hot connecting rod bearing.—When the large end of the connecting rod becomes very hot, the bearing and the crank then adhere to each other at the surface, and at each turn of the crank it tears away the solid metal, to the great danger of breaking the straps, keys, or even the rod itself, and thus leading to most extensive damage to the slide-motion, piston, and cylinder, if not to the boiler also. When it cannot be cooled while running, by throwing water upon it, and using oil and tallow to prevent adhesion of the metals, the engine must be stopped, the rod taken off, the slide fixed over the ports, and the engine-man can then proceed, according to circumstances, with one cylinder, as before, until relieved by the first pilot engine. In most cases, the engine-man, by reducing his speed, and carefully cooling and oiling the hot bearing, will be enabled to proceed until he comes to a stopping station. If by this heating, or by any other means, an eccentric becomes loose, it must be shifted back to its place as marked on the axle, and screwed fast again.

Hot axle-bearing.—When an axle-bearing becomes very hot, the train must be stopped, and the box cooled by water from the tender. The oil or grease-holes must then be cleared, and the box filled up with tallow and oil, which, by renewing at each stopping station, will usually carry the engine, tender, or carriage, safely to the end of the trip. However, should the means used to cool the bearing not succeed, the engine-man must stop at the first pilot station, and allow the pilot engine to take his train.

In most cases, it will not even be necessary to stop the train until it reaches a station, when the bearing can be cooled, and the box filled as above.

Broken leading axle.—When a leading axle breaks, the engine must be stopped, the fire drawn, and assistance obtained to clear the road and forward the train. If the engine is off the rails, the first object is to clear the way for the train to proceed, the engine being got on afterwards.

Going off the rails.—When both engine and tender are thrown off the rails, it is a work of time to get them on again; and the fire must be dropped, and water run off to lighten the engine and save the boiler. Assistance must then be obtained to clear the line, if obstructed, and to forward the train to its destination. After this has been done, the engine and tender must be separated, and got on to the rails separately, by raising them, by means of screw-jacks, until a temporary railway can be laid from under the wheels on to the main line. By this means they may be gradually drawn or pushed on to the road again, according to the position they are placed in.

Broken crank.—When a crank-axle breaks very badly, the engine must be stopped, the connecting-rod taken off, and the slide fixed over the ports. If it is broken at the side of the bearing for the connecting rod, and the stay bearings are good, the engine-man will still be able to go on with the train, if a light one, or seek assistance, if it is a heavy one. If the crank is so broken that the other engine cannot work, then the fire must be drawn, and assistance obtained in the usual way.

Broken trailing axle.—When a trailing or hind axle breaks, the engine must be stopped, and the springs and axle-boxes blocked up, so as to keep the wheels as upright as possible. The ends of the axle must then be suspended at a proper height to the foot-plate by a rope, when the engine can proceed with the train cautiously, until relieved by a pilot engine.

Broken wheel or tire.—When a wheel or tire breaks, the engine must be stopped, and assistance obtained to forward the train. If a driving-wheel tire, the wheel must be lifted up by the screw-jack, and blocked up to the proper level, when the engine, will be able to move itself, if not the train, out of the way. If it is a leading wheel, or tire, of a four or six-wheeled engine, it may probably be thrown off the rails, and, after the train has been forwarded, the engine must be got on to the rails again, as already described.

Apprehension of danger.—In case of the stoppage of either line of rail, from any cause, or apprehension of danger, whether in foggy weather or otherwise, the policeman on duty must place a detonator on the line or lines of rails so obstructed, every 200 yards from the point of danger, until they are protected for at least a mile.

Caution to stoppage signals.—In all these, or any other accident causing a stoppage, due care must be taken that the signals for a stoppage are immediately attended to, in order to prevent any following train coming into collision with the one which ha stopped.

FOGS.

Caution at stations.—During a fog, when an engine or train stops at a station, some person must be sent back half a mile, and place a detonating signal on the rail, to stop any engine or train coming up, until the other has started from the station. Detonating signals must also be used in a similar manner whenever any engine or train is following too closely upon another engine or train, or in any case of emergency or of danger.

Attention to detonators.—Whenever an engine passes over one of these signals, it explodes with a loud report, and the engine-man must then immediately stop the train. The guards of that train must likewise protect it, by sending back and placing these signals every 200 yards, as before, until they have extended a mile from the train.

Removal of detonators.—After the obstruction is removed, the policeman, guard, or fire-man must remove all the signals from the rails before proceeding.

Distance between engines.—No engine or train must leave a station during a fog, less than ten minutes after any preceding engine or train; and the policeman on duty must give the engine-man the exact time when the train started, and where it is next to stop.

Caution for signals.—Engine-men must always exercise great caution in foggy weather, and especially in approaching stations, from the difficulty of discerning the regular signals until close upon them; and they must be prepared to bring their engines to a stand before reaching the signal, whenever it is required.

DESCENDING INCLINES.

Attention to brakes.—In descending inclined planes, engine-men, fire-men, guards, and brakes-men, must take care that they have complete control over the speed of the trains, by having the brakes screwed up so far as to be able, by a single turn of the handle, to apply them forcibly to the wheels, when required to do so. The engine-man must not, however, place too much dependence upon the assistance he may get from the carriage-brakes, but keep the train perfectly under his own control by shutting off the steam in time.

Speed.—No engine or train should descend a steep incline at a greater speed than from 20 to 30 miles an hour, unless by special orders. With very heavy trains, the speed should not exceed 20 to 25 miles an hour; and no attempt should be made to make up lost time in going down an incline.

The usual speeds down inclines from 1 in 80 to 1 in 100, are from 20 to 30 miles

an hour, according to circumstances. On inclines from 1 in 37 to 1 in 80, they vary from 10 to 20 miles an hour. At the Wapping Tunnel, Liverpool, the speed is only 4 to 5 miles an hour.

ASCENDING INCLINES.

Dividing trains.—When inclines are so severe as to require the train to be divided, and taken up at twice, it must be done in the following manner: The part of the train to be left must be pushed into the siding at the bottom of the incline, clear of the main line; the first part must then be taken up the incline, and placed in the siding at the top. The engine or engines will then cross over to return on the proper line for the second part of the train. When this is taken to the top of the incline, it must be left on the main line, clear of the siding, and the first part of the train taken out and coupled to it: by this means the waggons will be again in their proper positions in the train.

Great care must be taken that the last portion of the train is not allowed to run down the incline after the engine is uncoupled from it.

Overtaking divided trains.—In the event of any waggons being left upon the main line, at the foot of any incline, and a succeeding engine coming up, such engine must not commence propelling or drawing the said waggons until the engine which left them shall have returned to take them away.

Returning on right road.—The assistant engine must invariably return down the proper line, and must always stand at the proper place, ready with the tender well supplied with coke and water, having the steam up, and the front of the engine towards the incline.

Assisting passenger trains.—When a passenger train requires assistance up an incline, the train must be stopped, and the assistant engine coupled on in front of the train engine, and both work together up the incline; and when fairly clear of the incline, the assistant engine must be uncoupled from the train engine, and proceed ahead to the first crossing, where it will pass over to return on the right line to its station at the bottom of the incline.

Assisting goods trains.—When a goods train requires assistance, it is usually given behind, as it takes a great part of the weight off the front waggon drag-chains; and, in the event of any of the drag-chains giving way, prevents these waggons from descending the line, which they would do, without any check or control, if the engine were ahead.

Great care must be taken by the assistant engine-man behind, to prevent any over-pushing of his engine, in case any waggon break down between him and the other engine. It is best when all assistance can be given ahead of the train.

Caution to pilot-man.—In moving out of the siding to assist a goods train up an incline, the pilot engine-man must take great care that the train has passed, before he comes near the main line, so as not to strike the train sideways before it passes clear of the pilot engine. As soon as it has passed, he must move out, and approach the end of the train with great caution, so as not to run against it with any force, and must give instant attention to any signal from the leading engine-man.

Responsibility of engine-man.—No engine-man should attempt to ascend, without assistance, any incline with a greater load than his engine is quite capable of taking up with certainty; and, as this varies very much with the state of the weather, the gradients, and the rails, the engine-man must decide for himself, in each case, whether he requires assistance, or not, and act accordingly.

EXTRA INCLINES.

Brakes-men.—When trains arrive at very steep inclines, either in or out of tunnels,

such as those on the London and North-Western Railway, where stationary power is used to drag them up the incline, or such as the Lickey incline, on the Birmingham and Bristol Railway, they are placed under the charge of special brakes-men, who have instructions in each case, which they must strictly attend to, both as to the speed, and number of carriages or waggons, according to the nature of the traffic to be taken up or down these inclines.

General regulation.—As a general rule, no train is allowed to go up or down without one of these brakes-men, whose duty it is to examine all the brakes, and satisfy himself that they are in proper order, with sufficient men to work them, before he starts a train either to go up or down one of these inclines. The speed is usually limited from 4 to 10 miles an hour, according to circumstances, and the brakes-men must at all times, whether going up or down, be sure that they have the train under perfect control with the brakes, in the event of anything giving way.

TUNNELS.

Approached cautiously.—All tunnels must be approached cautiously; so that if a signal is made to stop, the train may be stopped before entering the tunnel. Every engine-man must use his whistle before entering and while passing through a tunnel, to give proper notice to the policeman at the entrance, and to any man who may be employed in the tunnel.

Stoppage in tunnels.—When an engine or train breaks down in a tunnel, the torches must be lighted to ascertain the nature and extent of the accident, which must then be remedied according to instructions in preceding rules. Great care must be taken to protect the line both ways, to prevent collision and injury to the men at work, until the line is cleared and the train forwarded.

JUNCTIONS.

Signals.—In approaching junctions, every engine-man must blow the whistle at least a mile from the junction, and continue to do so until the policeman in charge of the junction points gives the proper signal that the main line is clear, when the engine-man can proceed on to it with the engine or train, at a speed not exceeding from 5 to 8 miles an hour. If, however, the signal be given that the main line is obstructed, then the engine-man must immediately stop the engine or train until the obstruction be removed, and the 'all-right' signal be shewn, when he can proceed slowly on the main line, as before.

Approached cautiously.—Every engine or train must approach the junction of two lines with great caution, and at a very slow speed, so as to stop altogether before reaching the junction, if necessary. In foggy weather, the engine-man must bring the engine or train to a stand before arriving at the junction, and not go on to the main line until he has learned from the policeman on duty how long the preceding train has passed, and he must stop or proceed, according to the information he receives.

REPORTS.

State of engine, &c.—The engine-man must examine his engine at the end of his trip, in the same manner as he did before starting, and report to the foreman on duty, or his clerk, anything he may observe or know to be wrong, and enter the particulars in the report-book kept for that purpose. He must also report every unusual circumstance which may have taken place on the journey, in the same manner.

Spare stores replaced.—Every engine-man must have replaced, before starting with his train, any spare stores he may have used, and he must have any broken tools made good again. He must also see that his lamps are taken to the appointed place to be cleaned and trimmed again.

DUTIES IN SHED.

Regulation of weight.—The weight of every engine should be properly distributed on the wheels and springs. No engine can run steadily with one, two, or three tons more weight upon one spring than upon the opposite one. A six-lever weighing machine should be on all extensive railways for this purpose, by which the weight on each wheel can be regulated with great nicety. For passenger-train engines, there should be nearly as much weight on the leading as on the driving wheels. Eight-wheeled engines have more weight on the two leading than on the driving wheels. All the weight required on the driving wheels is as much as to produce sufficient adhesion, in ordinary cases, to draw the train, as there are times when all the weight would not prevent slipping. For all ordinary trains, the engine will run the whole distance in less time and more steadily with lightly-loaded driving wheels; for any time lost in starting is more than made up afterwards by the ease given to the machinery. Four- and six-wheeled coupled engines have generally all the weight brought into action for power, and not for speed; and it is therefore more equally distributed over the wheels.

Hand-pump to be tried.—Every engine-man, when in the shed, should try his hand-pump, to insure himself that it is in good order, as, being seldom required, they are liable to become 'furred up' with the deposit from the water, and in that case of no service in any emergency.

Cleaning boiler.—The boiler should be regularly blown out, over the pit provided for that purpose, at such times as the state of the water requires, which the engine-man can readily determine from experience. The boiler must also be washed out with cold water, at least once a week, to remove all loose deposit from it. Muriate of ammonia is used for preventing the adhesion of deposit to the boiler, which it effects by keeping the lime in solution, and which is blown out two or three times a week, according to the purity of the water used for the generation of the steam.

Adjustment of machinery.—Every engine-man, when in the shed, must carefully examine his engine; and, when necessary, adjust the piston, slides, connecting-rod bearings, axle bearings, springs, or any other part requiring adjustment, and see that the eccentric sheaves are all fast in their right places.

Trimming stuffing-boxes and syphons.—He must also pack his stuffing-boxes, examine his clacks and feed-pipes, clean and trim his syphons, so that he may have his engine in good working order when required to go on duty again.

PILOTING.

Tools.—Pilot engine-men must at all times, during the hours appointed for them to pilot, stand ready to start at once, with their steam up, their tender full of coke and water, and be provided with the following tools; namely, two pinch-bars, two screw-jacks, a large drag-chain, a rope, two signal lamps, two hand-lamps and detonators. One of the signal lamps to be put on the front of the engine, and the other behind the tender, and the hand-lamps to be used as signals, or as may be required.

Orders.—When it is necessary to send the pilot engine to look for a train, a regular order must be made out for it; and if at or near to night, both lamps must be lighted, and a red light shewn behind and a green one in front. When the pilot engine-man meets with the train, if it be at a stand, he must ascertain the cause, shew red lights both ways, and run on to the next crossing ahead. He must then cross, returning to give every assistance he can, whether the engine be broken down, or any part of the train be off the line, or to push the train slowly before him until he can put it into a siding, and get in front of it, which he must do on the first opportunity.

Caution on crossing line.—No pilot-man in search of a train, past-due, must cross

on to the main line until the danger signals are turned on, and then only when he has ascertained from the policeman on duty that he can do so with safety, to prevent collision in case of the train coming up at the moment of crossing.

Orders countersigned.—When any pilot engine is sent out, on its arrival at the next pilot-station the engine-man must shew his order to the foreman on duty at such station, and either obtain a fresh order, or have the old one countersigned by the foreman, before he proceeds further.

Speed.—Any engine-man proceeding along the line with an order must be careful to proceed at the same average rate of speed as the passenger trains, and on no account to run his engine at a higher speed at any part of his journey, unless otherwise specially instructed in his order.

Assistance.—If both lines are obstructed, he must assist in clearing the lines, and then receive instructions for his further movements from the first guard, or his superior officer, being careful not to return on the wrong line until he has satisfied himself that the police have been made aware of the circumstance for the whole distance he has to go on the wrong line; and he must then proceed slowly, sounding his whistle every quarter of a mile during the whole time.

Responsibility.—When any engine is sent on the line with an order, without any train, or from any other cause, without a guard, the engine-man will be entirely responsible for all the movements of the engine; and, in addition to the precautions and rules ordinarily applying to him, he must, in the event of being compelled to stop, send back the fire-man to make all the usual signals, as already described for stoppages. The fire-man must not return until he meets and is relieved by the next policeman. If the engine-man is obliged to cross over to the other line, and is some distance from a crossing, he must always move forward on the proper line to the next crossing, and never return on the wrong line.

SECTION IV.—DESCRIPTION OF THE 'LORD OF THE ISLES' AND THE 'LIVERPOOL' LOCOMOTIVE ENGINES.*

'LORD OF THE ISLES' BROAD-GAUGE LOCOMOTIVE ENGINE.

This fine powerful locomotive was exhibited in the Crystal Palace by the Great Western Railway Company, of which Mr. Brunel is engineer. As a massive example of Stephenson's class of locomotives and good workmanship, it is creditable to the Swindon Railway Works, where it was made, and an ordinary prize medal was awarded to the Exhibitors. After the expectation held out, that the broad gauge would be the means of introducing some decided novelty or improvement in locomotives, not a few were disappointed to find that the 'Lord of the Isles' only embodied narrow-gauge improvements, and had been surpassed in originality, in heating surface, and in a low centre of gravity, by Crampton's narrow-gauge engine the 'Liverpool.' It is however known that Mr. Brunel at first sought to introduce originality in the construction of locomotives, as well as in the width between the rails; but before he got the locomotives fairly organised, his innovations were attacked by a powerful narrow-gauge force.† During this attack, the command of the broad-gauge engines was held by a pupil of the chief attacking officer (Mr. Stephenson),‡ to whom Mr. Brunel appears to have at once surrendered the locomotives to be Stephensonised,—as they soon were,—and concentrated his energies to defend the width of gauge only. With considerable difficulty this has been done, and necessarily insures comparatively greater safety from a greater width of base, being as 84 inches to 56½ inches, or

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* By John Sewell, C.E.

† Wood and Hawkshaw's Reports, 1838.

‡ Gauge Evidence. Quest. 2226. 1845.

nearly as $1\frac{1}{2}$ to 1 in favour of the broad gauge. But in all the past gauge trials of locomotives in 1838, 1845–6–7, the difference in speed has been merely one of degree, slightly in favour of the broad gauge, high wheels, and large boilers, at extreme velocities; but for practical every-day duty, with numerous stoppages, the advantages are on the side of lower wheels on both gauges.

The late Mr. George Stephenson considered the general introduction of his form of engines on the broad gauge as a great triumph, and many engineers now regard Crampton's 'Liverpool' as shewing the capability of the narrow gauge in producing a good working engine of a power, a height of wheels, and safety at high velocities, equal to the 'Lord of the Isles' class of engines. It is, however, worthy of notice, that if Mr. Crampton was not a pupil of Mr. Brunel, he was at least some time in his locomotive office at Paddington, where he first brought out the design of the 'Liverpool' without success, until the gauge contest of 1845 brought it under the favourable notice of the London and North-Western Railway Directors. The separate crank-axle of Mr. Crampton's 'Folkstone' locomotive is also one of Mr. Brunel's early plans, which was taken out of two engines to Stephensonise them. The only difference is, that Mr. Crampton uses a side-rod whilst Mr. Brunel used toothed-wheels to connect the respective axles. For these two designs, as embodied in the 'Liverpool' and 'Folkstone,' Mr. Crampton received the highest class or Council medal of the Great Exhibition.

Description of the Engravings.

Fig. 1 is a longitudinal section, shewing the general arrangement and outline of the 'Lord of the Isles' engine.

Fig. 2 is a transverse section through the front and back fire-places on each side of the central water partition D, in fig. 1.

Fig. 3 is a transverse section through the smoke-box G, and cylinder M, steam pipe I, and blast pipe X, fig. 1; also through the steam chest *q q* and slide valves N N fig. 3.

The same letters apply to the same parts in each figure.

Fig. 1.—A represents the cylindrical part of the boiler, 10 feet 9 inches long by 4 feet 10 inches in diameter, made of the best wrought-iron plates, well riveted together: B is the rectangular fire-box case, with a semicircular top, as seen in figs. 2, 3, also made of best wrought-iron plates, and securely riveted to the horizontal part A by means of a strong angle-iron; G, the rectangular smoke or cylinder box with a semicircular top, as seen in fig. 3, also well riveted to the boiler. Viewed externally, these three separate divisions form the complete outline of the boiler, to which the machinery is attached. Internally, C is the copper fire-box fixed to the outside case B at its lowest edge by a double row of rivets. Immediately above these rivets the copper is bent inwards, as seen in figs. 1 and 2, so as to leave a water space averaging about 3 inches wide all round between the fire-box C and outside case B. As these flat sides present a large surface in a weak form to the force of the steam, they are strongly tied together by numerous copper stays *d d*, screwed through both plates and the ends riveted over, as shewn in the upper side part C of the fire-box, fig. 1, or lower back part *d*, on the right-hand side of fig. 2.

In fig. 1, *e* is a side view of one of the strong wrought-iron stays which rest on the vertical sides of the copper fire-box and support its flat top, which is strongly bolted to it, as shown in the figure, or sectionally in fig. 2.

n', fig. 1, is one of ten longitudinal wrought-iron stays which tie together the flat ends of the boiler, so as to resist the force of the steam. In fig. 2 they are sectionally seen at *n*, *n'*, between the fire-box top stays *e e*. In all steam boilers the flat

surfaces require to be very strongly stayed for security, which will be apparent when

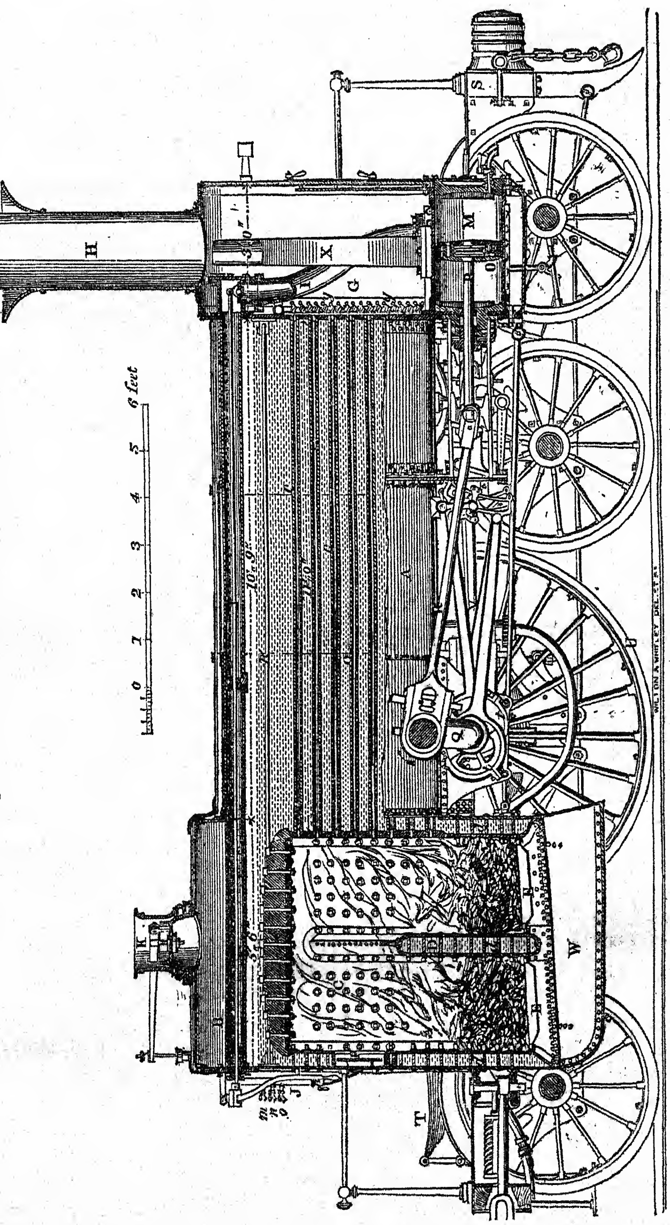
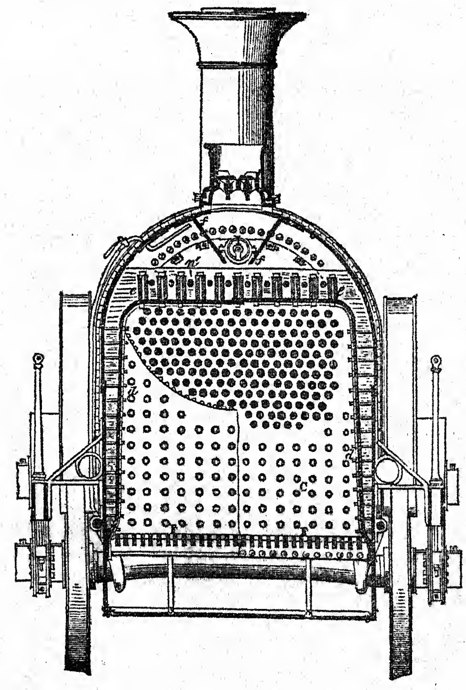


Fig. 1.—Longitudinal Section of the 'Lord of the Isles.'

it is stated that at a pressure of 100 lbs. per square inch, the 'Lord of the Isles boiler-case and fire-box would have to resist a force of about 3125 tons.

D is a transversewater partition about 4 inches wide, which divides the lower part of the fire-box C into two separate fire-places E E; the flat copper sides are firmly screwed and riveted together by the copper stays *d*, fig. 1, or at *d*, fig. 2, left-hand side. Transversely, as seen in fig. 2, it is curved upwards from the centre at each side towards the top of the fire-box C, to which it is riveted, as shewn in the figure, while the right-hand side shews the back of the fire-box below the tubular flues; E E, the two separate fire-grate bars, figs. 1 and 2; F, the door by which fuel is supplied to the first-places; *c c c*, fig. 1, the tubular flues, 305 in number, each 11 feet long by 2 inches outside diameter, through which the products of combustion pass from the fire-box C to the chimney. In fig. 2 their relative position to each other is seen, with the first row commencing immediately below the top of the fire-box C: G, the smoke-box, in which are placed the cylinders, steam-chest, blast-pipe, and steam-pipe. On the top of the smoke-box, and with its centre vertical to the blast-pipe orifice, is placed the chimney H.

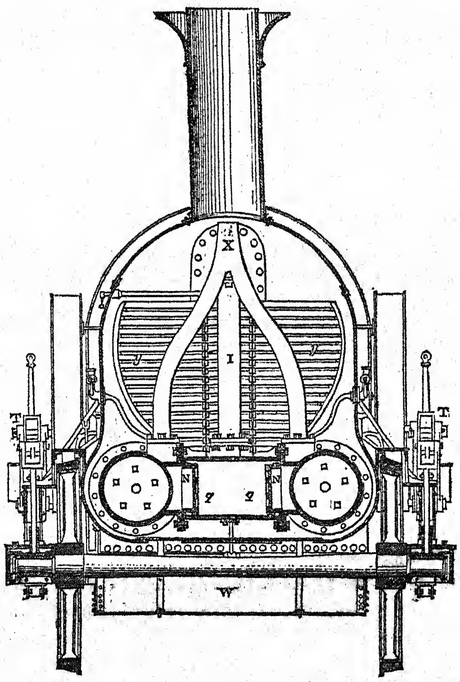
Fig. 2.—Transverse Section through the Fire-places.



I is the steam pipe, turned at right angles where it enters the smoke-box, and continued to the steam-chest *q q*, fig. 3. The horizontal part extends all the length of the boiler and fire-box, and receives the steam at numerous small holes or thin narrow slits on the upper side, to avoid the oscillation of the water in the boiler when the pressure is either suddenly relieved at one part by turning the steam on to the cylinders, or increased by shutting it off from them. This was one of Hawthorn's patents. The regulator handle is shewn as bent down past the gauge cocks *m*, *n*, *o*, and glass gauge J. A rod passes from the handle along the centre of the steam pipe I to the regular valve placed at the top of the vertical part of the steam pipe I in the smoke-box, as shewn in fig. 1, or its cover at the back of the blast pipe X, fig. 3. In fig. 2, the transverse position of the steam pipe is clearly seen guarded by the water 'baffle' plates *f f*, so placed to prevent any considerable body of water rising over the pipe or entering it with the steam. Near the 'baffle' plate *f* on the left-hand side of fig. 2, is seen the end of the small steam-pipe for conveying the spare steam to heat the feed water in the tender, where it makes a peculiar rattling noise when turned on by opening the cock seen outside the boiler on the same side. J is the glass gauge tube fitted nicely into two brass

sockets attached to the front end of the fire-box case B. The upper end is open to the steam and the lower end to the water, by which means the relative heights of the water and steam are seen by the driver. *m, n, o,* are three gauge cocks fitted into a brass tubeplaced parallel to the glass tube. The upper one, *m,* opens to the steam, and the two lower ones, *n, o,* to the water, so that in case of accident to the glass tube they may be used to guide the driver in managing the engine. K is one of the two safety valves placed side by side, as shewn fig. 2, where a lever is attached at its extremity to one of Salter's spiral spring weighing machines, partly seen, by whose indication the pressure on the valve is regulated. This valve is under the control of the driver to lessen the pressure, but only very limitedly so to increase it. The other safety valve is regulated by a spiral spring placed vertically over it, and screwed down to give about 5 lbs. more pressure per square inch than the steelyard lever safety valve, at which the steam should first blow off. This last valve is not under the control of the driver at all.

Fig. 3.—Transverse Section through the Smoke-Box, &c.



M is the cylinder, in which is fitted steam-tight the piston O, fig. 1, whose flat ends are shewn in the transverse section of both cylinders in fig. 3, where N N are the two slide valves which regulate the admission of the steam to the cylinders, and its escape from the cylinders to the atmosphere.

They are of the usual D class, elevated in the centre and planed flat faces on the sides, for sliding steam-tight against the faces of the cylinders, surrounding the steam passages to the cylinders and atmosphere. There are three of these passages, of which one at each end admits steam to or from the cylinders, and one in the centre, open to the atmosphere through the blast pipe X. When in a central position, these three passages or 'ports,' as they are frequently called, are all covered by the slide valves N N. On these valves being moved until a portion of one of the end passages is open, the steam enters the cylinders and presses the piston O before it, whilst the steam on the opposite side of the piston escapes by the opposite end port, past the inner edge of the elevated part of the valve, through the central port and blast pipe X into the chimney H. During the return stroke, a similar action takes place from the opposite ends of the cylinders, and the time taken in these separate acts is distinctly conveyed to the ear by the separate 'beats' or concussions of the escaping steam against the air in the chimney.

At the back of the driving-wheel guard-covers, on each side of the boiler, fig. 3, is a cup, with a bent pipe inside the smoke-box, to convey tallow to lubricate each slide valve N N. P is the piston rod, whose end is keyed or screwed into the cross-head or guide which moves in a line with the cylinder between the two guide-bars shewn in fig. 1. The opposite side of this cross-head guard has a spherical bearing which is grasped by a concave bearing, keyed on to the end of the connecting rod R, whose other end is also keyed into a cylindrical bearing which grasps the crank Q, of 12 inches throw. On this cranked axle the driving or propelling wheels U are fixed.

The pumps are not shewn, but are placed in a line with the motion bar, and worked directly from the cross-head.

To the front end of the frame S are attached two leather 'buffers' filled with hair, coir, and cork shavings; also the rail-guards below, to clear off any obstructing body on the rails. One of each is shewn in the figure, as well as the drag-chain for coupling the engine to another vehicle.

T, fig. 1, is one of the eight springs which form the elastic base of $20 \times 7\frac{1}{4} = 145$ feet that supports the boiler and machinery on the eight wheels. T T fig. 3, are sections of the two leading springs connected to the frame mid-way between the two pairs of leading-wheels by vertical links from the centres of the springs. Each end of these leading-springs is supported by a vertical rod resting upon one axle-box of each pair of wheels, so that one spring on each side sustains the weight of the front end of the engine on the two pairs of wheels. One of the four driving-wheel springs is partially seen in fig. 1, with its centre connected to the under-side of the axle-box and its ends connected to the frame by a hooked screw-bolt, to regulate the weight upon these wheels. Of the others, one is opposite and two above the axle under the frame.

U is one of the driving-wheels, 8 feet diameter, made entirely out of malleable iron scraps, with a plain steeled tire outside, slightly shrunk on and further secured by the set-screws shewn in the figures. The other wheels are $4\frac{1}{2}$ feet in diameter, also made from scrap iron, and having steeled tires with flanges on them, to guide the engine on the rails.

In fig. 2, the elevation of the driving-wheel, guards, hand-rail guides, and side stays which fix the boiler to the frame resting on the axle-boxes by the spring pins, are seen on each side. In fig. 3 the front axle, axle-boxes, side stays, and springs are shewn sectionally, with the driving-wheel, guards, and hand-rail supports in elevation: V is the connecting-rod of the opposite engine on the centre or powerless point where the crank Q and connecting-rod R are exerting their greatest power. Below R, and on each side of V, are seen the eccentric rods connected to the suspended curved 'link,' which works the slide valves N N, on the plan called the 'link motion,' first successfully introduced by Mr. Gray on the Hull and Selby Railway, which success led to its modification and general adoption on most locomotives.

The object of the 'link motion' is to enable the driver to vary the quantity of steam admitted to the cylinders according to the load against the pistons, which it does by giving the slide valves more or less travel according as they are worked from the centre of the curved link or any part towards its extremity. When worked from the extremity, the travel is greatest and the steam-port longest open, which admits most steam to the cylinder, to overcome heavy loads, gradients, or starting. As the slide-valve connecting-block is moved nearer and nearer to the centre of the link, the travel of the slide-valve becomes less and less, thereby cutting off the steam sooner and sooner from the cylinder, to promote economy in working the engine.

A lever handle, placed conveniently for the engine-driver, is connected by a long side rod to the vertical arm of a bell-crank shaft. The slide-valve links are attached

to the horizontal arms of this shaft, one of which is seen above the centre of the second front wheel, in fig. 1. As the driver, therefore, moves the lever handle from the centre 'notch' or catch which retains it, the position of the valve connecting link is varied by its end sliding up or down in the curved link. The motion is so arranged that when the handle is moved towards the front, the engine is in forward gear, and runs in that direction; but when the handle is moved from the centre backwards, the engine is in backward gear, and runs backward.

W is the ashpan fitted up against the lower edge of the fire-box case B, to receive the ashes or cinders falling from the fire-grates E E. The bevelled side toward the front is closed with a flap-door when not working, to prevent unnecessary combustion by excluding the air; but when running, this flap is opened by the driver, to admit air to pass through the fire, and promote combustion.

X is the blast pipe for conveying the steam from each cylinder to the atmosphere, so as to promote a rapid combustion of fuel and generation of steam. As shewn in fig. 3, the two pipes are joined together near the upper extremity, to form only one orifice, 5½ inches diameter, central with the chimney. This orifice is regulated in diameter by the quantity of steam required in a given time. If the boiler possesses large generating power compared with the duty it has to perform, the blast pipe can be enlarged; but if the boiler's steaming power is small as regards the duty, the blast pipe has to be reduced in size to increase the velocity of the escaping jets of steam up the chimney, and consequently the velocity of the air through the fire, to promote more rapid combustion. Since the compression of the escaping steam through the blast pipe causes an opposing or back pressure in the cylinder against the piston, it is a desideratum to make it as large as can be done, to make that back pressure as limited as possible. In the 'Lord of the Isles' class, at all velocities below 40 miles an hour, the back pressure little exceeds that of the atmosphere, which of course is a constant pressure; but after the exhaust or escape port is closed, the atmospheric pressure of 15lbs. is compressed until it reaches at the last instant a considerable amount, ready to act in propelling the piston the moment it commences its return stroke.

This important yet simple part of a locomotive engine was first practically introduced in railway locomotives by Mr. Hackworth, and first prominently exhibited by him at the Liverpool trial of locomotives in 1829.

In fig. 3, *y y* is a series of iron strips fitted up similarly to a Venetian window-blind, which are raised to stand out parallel with the tubes when the engine is at work, but shut down over the tubes when not at work, as seen in fig. 3. The manner of their jointing to the closing and opening rods is shewn sectionally at *y y*, fig. 1. The lever by which this is done is seen at the left-hand side, and is connected by a side rod to a handle within the reach of the driver. The outside circle shews the relative diameter of the top of the fire-box case B, fig. 1, to that of the smoke-box G, on which the chimney is fitted.

The principal inventions embodied in this engine are modifications of Brunel's high wheels, Stephenson's fire-box, tubular flues, slide-valve arrangement, and springs; Hawthorn's steam pipe and four separate eccentrics; Gray's expansive valve motion, Hackworth's blast pipe, Papin's steelyard or lever safety valve, and Rastrick's lock-up safety valve.

The fire-box heating surface is 156 square feet, and the tubular flue heating surface 1759 square feet, or a total heating surface of 1915 square feet. The cylinders are each 18 inches diameter and 24 inches stroke, with a driving wheel 8 feet diameter.

The extreme evaporative power is stated as 1000 horses, and the effective power as 743 horses.

With an ordinary mail train of 90 tons, at 29 miles an hour, the consumption of coke has averaged 20·8 lbs. per mile.

This consumption is, however, evidently not an average consumption for average work, but that due to a special train under favouring circumstances. The real average consumption of coke per mile will be from 40 to 50 per cent. higher, or from 28 to 30 lbs. per mile. Such is the influence of a few miles' greater speed per hour, and ordinary contingencies, in all locomotives, without reference to gauge.

CRAMPTON'S PATENT LOCOMOTIVES.

In describing the 'Lord of the Isles' broad-gauge engine, we have referred to the circumstances which first brought this class of engines into public notice. Before that time, the general practice was to place the driving wheels below the cylindrical part of the boiler, as adopted by Mr. Stephenson soon after the locomotive trial on the Liverpool and Manchester Railway in 1829. Mr. Crampton's proposal to place them behind the fire-box, and lower the boiler altogether, met with no favour at first from the adherents to the older form. The exigencies, however, of the narrow gauge overcame the prejudice existing against his engines, which are now acknowledged as a valuable class both in England and on the Continent. In England, the 'Liverpool,' constructed by Messrs. Bury and Co. on Crampton's patent, is the most powerful of them yet made, having cylinders of 18 inches diameter and 24 inches stroke, with driving wheels of 8 feet diameter. The heating surface is in proportion, amounting to 154 square feet of fire-box, and 2131 square feet of tubular flue heating surface, making a total of 2285 square feet, or about 370 square feet more than in the 'Lord of the Isles,' with equal-sized cylinders and driving wheels. The weights of these two engines are nearly alike, only varying about one ton, the 'Liverpool' being stated as 32 tons, and the 'Lord of the Isles' as 31 tons.

For symmetrical appearance, the 'Liverpool' has a less bold and pleasing outline than the engines of Stephenson's form, as exemplified in the 'Lord of the Isles.' However, what is thus lost in appearance is gained in safety, by lowering the boiler until the relative centre of gravity is lower for a narrow-gauge engine than for the existing broad-gauge engines. To those who had an opportunity of seeing both the above-named engines in the Crystal Palace, this would be evident, and constitutes their chief difference from the usual form on both gauges. It is also the low centre of gravity and position of the driving-wheels which enables them to compete with the broad gauge in power and safety within the limits of weight economically sustainable by the rails and permanent way. In the new edition of Tredgold there are elaborate engravings of the 'Liverpool,' as exhibited by the London and North Western Railway Company in the Industrial Palace, Hyde Park. This engine, it may be remarked, worked well, but was laid aside, along with another large 8-wheeled engine of Mr. Stephenson's, as too heavy for the roadway. The Great Western Railway Company, however, persevere in working their large engines at 110 lbs. pressure of steam, regarding them as more economical for the heavy traffic of the London end of the railway than the smaller engines worked at only 75 lbs. pressure. Deducting the atmospheric pressure of 15 lbs. from each, it gives, for equal-sized cylinders, a working pressure of 95 lbs. to 60 lbs., or as 1 to 1·58 in favour of the large engine, without reference to size of cylinder.

Description of the Engravings.

Fig. 4 is a side elevation, shewing the general appearance of the engine and arrangement of the wheels and machinery.

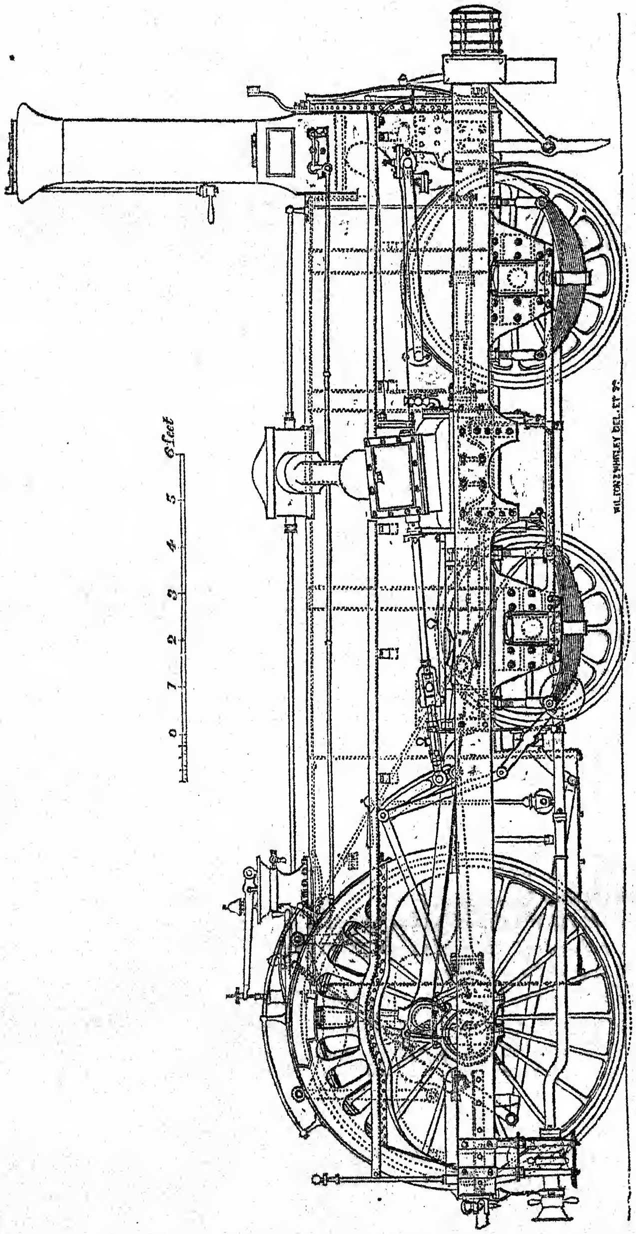


Fig. 4.—The 'Liverpool,' constructed on Crampton's Patent.

The principal dimensions of this engine are,—cylinders 15 inches diameter and

21 inches stroke, with driving wheels 7 feet diameter. The middle wheels are 3 feet diameter and 8½ feet in front of the driving wheels. The front wheels are 4½ feet diameter and 7½ feet from the middle wheels. The base resting on the rails is therefore 16 feet in length by 5 feet in width to the centre of the rails. The base resting on the springs is 19 feet in length by 8 feet in width, and the area of the entire frame 24 feet by 8 feet wide. The frame is made of two wrought-iron plates 8½ inches deep by 1 inch thick, and 22 inches apart on each side. Within this double frame the wheels are placed, having inside axle-bearings for the driving wheels and outside axle-bearings for the two pairs of supporting wheels. The side frames are strongly bound together by the foot-plate behind the fire-box, a curved stay-plate in front of it, two more where the cylinders are fixed, and two below the smoke-box. The front buffer bar is of oak, 6 inches thick, and curved down to 2½ feet deep, to clear the smoke-box door: it is strongly bolted to the sides of the frame, and has two stuffed leather buffers fixed in front of it. Viewed externally, the fire-box is 5 feet 1 inch long and 4 feet wide, with a semicircular top on a line with the boiler, which is also 4 feet diameter. Internally, the fire-box is 4 feet 5 inches deep, 3 feet 4 inches wide, and 4 feet 5 inches long. The top stays are 8 inches deep, well bolted to the top, and also fixed to the top and both ends of the outside boiler cases, besides resting on the vertical sides of the fire-box, similar to the 'Lord of the Isles.' The cylindrical part of the boiler is 4 feet diameter and 11½ feet long, containing 177 tubular flues, each 2 inches diameter and 11¾ feet long. It also contains the receiving steam pipe, extending all the length of the boiler, and 5 inches diameter, but only 3½ inches diameter over the fire-box. The flat ends of the fire-box case and smoke-box are further stayed together by six wrought-iron longitudinal stays. The connecting rods are 7½ feet in length, and the eccentric rods 5 feet long. The top of the boiler is 6 feet 10 inches from the rail, and 2 inches below the top of the driving wheels. The bottom edge of the fire-box is about 1 foot from the rails. The orifice of the blast pipe is 5 inches diameter, but is fitted up with the means of varying its size, by the rod seen alongside the boiler to a small crank near the chimney.

The average velocity realised with ordinary trains by this engine is about 45 miles per hour, and the extreme velocity about 63 miles per hour.

On examining the figure, it is seen that the top of the fire-box and central part of the boiler are parallel with each other, and the whole outline is much lower than the usual form of engine. The driving wheels are also observed with their axle immediately behind the fire-box and over the foot-plate. These are the two distinctive features of Crampton's engines, viz., a low centre of gravity and the driving wheel axle behind the fire-box. By this arrangement the greatest weight is placed on each pair of extreme wheels, and the least weight on the centre ones, to insure greater steadiness, and less risk of leaving the rails easily. For instance, there are about 10 tons on each pair of the driving and front wheels and only about 7 tons on the middle pair of wheels of this engine.

This is considered as a point gained in safety, by preventing that tendency to oscillate when the greatest weight is balanced on a central pair of driving wheels, whilst the hinder pair has only a nominal weight to support, or an overhanging fire-box without the check of a pair of wheels, as in Stephenson's long-boiler class.

It is the position of the driving-wheels and their diameter which determines the height of the boiler in the ordinary class of engines, and when these wheels are high and their axle cranked, the boiler is also necessarily high above the rails. The 'Lord of the Isles' is of this class, with a boiler 58 inches diameter, raised as far above the driving axle as to allow the cranks and connecting rods space to revolve round the axle, by which its height from the rail is about 9½ feet. With a boiler 60 inches deep

and driving wheels of the same height, the 'Liverpool' is only about $7\frac{1}{2}$ feet high from the rails.

In engines with the driving wheels behind the fire-box, the height of the boiler depends upon the diameter of the supporting wheels and the distance it is desirable to keep the lowest edge of the fire-box above the rail; hence the difference between the respective heights of the 'Liverpool' and the 'Lord of the Isles.' The annexed diagrams will more clearly explain the difference referred to. Fig. 5 is an outline of one of Stephenson's long-boiler engines, with driving wheel $6\frac{1}{2}$ feet diameter. In this class, the smoke-box overhangs the front wheels, and the fire-box overhangs the driving wheels, which are placed behind the supporting wheels. It may be noted that this alteration of the usual central position of the driving wheels by Stephenson materially aided Crampton in getting his plan tried, for it was obvious that greater safety and steadiness would be obtained by placing the wheels behind the fire-box than in front of it. In Stephenson's old short boiler engines the wheels were arranged otherwise, as if the middle wheels, fig. 5, were taken out and placed behind the fire-box, as in the 'Lord of the Isles.' Fig. 6 shews the transverse elevation of the boiler, fig. 5, whilst fig. 8 shews the relative height of a boiler over a cranked axle in wheels 8 feet diameter. Fig. 7 shews the comparative height of the boiler of one of Crampton's engines with 8-feet driving-wheels. The difference in point of safety is obvious.

Fig. 5.

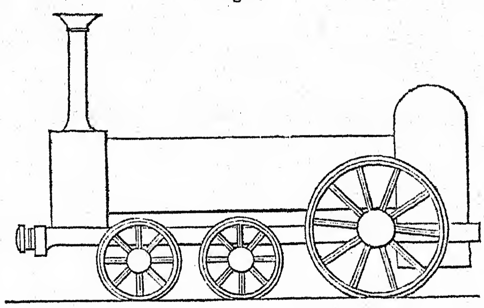
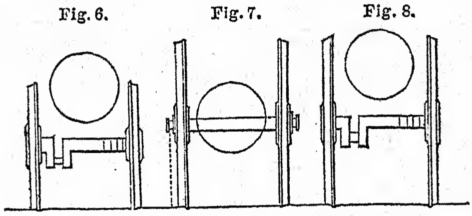


Fig. 6. Fig. 7. Fig. 8.



It is, however, evident that Crampton's plan could also be applied to the broad gauge, but under the disadvantage, already great enough for the narrow gauge, of increasing the distance from the centre line of progression to the centre line of propulsion by the cylinders. Inside-cylinder engines have these centres nearer each other, which tends to prevent oscillation with a high centre of gravity, and the cylinders are well protected from external cold in the smoke-box, whilst outside-cylinder engines are necessarily less protected, and more distant from the centre of progression. In a later patent Mr. Crampton has sought to obviate these disadvantages and still retain a comparatively low centre of gravity, by introducing a separate crank axle, as in Trevithick's first locomotive of 1803, and in two broad-gauge engines of 1838.

This plan is carried out in the 'Folkstone,' where the cylinders are placed in the smoke-box inside the frame, and the machinery of piston-rods, link motion, pumps, and cranked axle is placed below the boiler, as in the 'Lord of the Isles.' The cranked axle has no wheels on it, and is placed as low as is practicable, with its ends connected to the driving wheels behind by side rods, similar to luggage train engines.

For these combinations of locomotive machinery the Council medal of the Great Exhibition was awarded to Mr. Crampton, as the designer of the 'Liverpool' and the 'Folkstone' locomotive steam engines.

A considerable number of Crampton's engines are now employed, varying only slightly in detail from the example here given, and a few also on the plan embodied in the 'Folkstone.' The full detailed description of the 'Lord of the Isles' renders it unnecessary to do more than point out generally the similar details of Crampton's engines, which combine the same inventions as are in the 'Lord of the Isles,' with the differences already described.

In fig. 4 the length of the fire-box is shewn by vertical dotted lines; it is strongly stayed, and similarly constructed to that of the 'Lord of the Isles,' excepting that it has no divisional water space in the fire-box. The 'Liverpool' has however a longitudinal water space in the fire-box, open to the water at the top, and dividing the fire-box top into two parts, but only reaching downwards to within 7 inches of the fire-grate, which is therefore not divided as in the fire-box of the 'Lord of the Isles.'

The front of the tubes is also open to the products of combustion, whilst the upper parts of the fire-box sides are curved outwards to increase the tubular area of the boiler, as now also adopted in some broad-gauge engines. From this description it will be understood that the water partition of the Liverpool's fire-box is longitudinal from the top downwards, whilst it has been shewn that the water partition of the 'Lord of the Isles' is transverse and curved upwards from the bottom.

The position of the cylinders is seen between the front and middle wheels outside the boiler, and well fixed to the double frame. The steam pipe is seen passing from the regulator chest on the top of the boiler to the steam chest on the upper side of the cylinder. When the regulators are opened by the rod seen on the top of the boiler, the steam passes down the outside lateral pipes, $4\frac{3}{4}$ inches diameter, to the steam chest, where the slide valves distribute it to the cylinders. From the cylinders the steam escapes by the oblong circular passages below the slide valves, and along the pipe leading from the cylinder to the smoke-box, where the two side pipes are turned upwards and united to form the blast pipe. Immediately over the blast pipe is fixed the chimney, 15 inches in diameter, with a cover fitted on its top to check the draft on the fire when the engine is not working. The vertical rod and handle are seen by which the damper is turned off and on the chimney as required.

For want of this simple process of working this damper a fire-man was killed on the Great Western Railway, by his head being jammed between the chimney and the joist of the shed, as the engine moved from rest, whilst he climbed up to remove a loose plate by hand from the chimney-top.

Behind the middle wheel is seen the position of the piston rod, guide bars, and cross-head, with its union with the rod which connects it to the driving wheels on which the sheaves of the eccentric are fixed. Two of the four eccentrics are shewn with their rods jointed to the upper and lower end of the curved 'link' which is attached to the slide-valve rod by a slide block, moveable inside the link. As drawn, the lowest eccentric rod is in 'full gear' for working the slide valve. Behind the driving wheel is seen the reversing lever, with its connecting rod leading to the reversing shaft arm near the middle wheel, having another arm connected to the top of the curved link. By this hand-gear the driver moves the link up and down the slide-valve rod block to regulate the travel of the slide valve and expansive action of the steam to the duty it has to perform, as described in the link motion of the 'Lord of the Isles.'

To another arm on the same shaft, the circular weight is attached, to balance the weight of the shifting link and eccentric rods, so that they may both work and be

reversed with greater ease. When the 'link' is suspended from the boiler as in the 'Lord of the Isles,' the suspension rods sustain the eccentric rods and 'link,' so that no balance weight is required. From the lower sides at each end of the cylinders are placed cocks for allowing the condensed steam to escape, opened and shut by the rod seen passing angularly to the top of the driving wheel and within the reach of the driver.

The tallow cup for lubricating the piston and slide valve is seen at the upper right-hand corner of the cylinder.

Near the front corner of the fire-box is seen one of the blow-off cocks, for allowing the steam and hot water to be forcibly ejected, and carry down as much of the deposit precipitated by boiling as possible. The handle is seen over the top of the link, with its rod down to the cock key.

Above the frame, beside the front wheel, is seen the water-supply pump, with the pipe to the left which conveys the water into the boiler. The barrel of the pump is seen in dotted lines along the frame and in the same plane as the cylinder. The piston has two rods, one of which connects it to the driving wheels, and the other from the opposite end of the cylinder works the pump. The piston is thus supported from both ends, which prevents it from dropping down to rub along the lower side of the cylinder, as is frequently the case with heavy pistons on the end of a rod.

Below the axle-boxes of the wheels is seen the feed pipe leading from the pump to the tender water tank, and suspended from the frame and fire-box. It is connected to the tender feed pipe by a ball-and-socket pipe, partly seen near the steps up to the foot-plate of the engine. Three of the six springs supporting the engine on the wheels are shewn, two of them below and one above the frame. They are about 3 feet 3 inches long, connected by their ends to the frame, and by their centres to the axle-boxes. Over each of the wheels is a guard to prevent the driver from coming in contact with them whilst moving about on the engine, and those over the driving wheels protect the men on duty from side gales or storms. A hand-rail passes along from the driving-wheel guard to the smoke-box, for the men to lay hold of when going to the front of the engine.

Above the driving-wheel guard is seen one of the safety-valve levers, the 'locked-up' one being alongside of it.

In front of the chimney is seen the signal-lamp socket, and in front of the smoke-box the handle for opening and fastening the smoke-box door. Below the smoke-box is seen the rail-clearing guard, strongly bolted to the frames.

SECTION V.—ON THE DIMENSIONS OF THE LOCOMOTIVE ENGINE BOILER IN RELATION TO ITS EVAPORATIVE POWER.*

"In the fire-box and boiler resides the real source of the power of the engine."—PAMBOUR.

1. The object of this Section is to determine the dimensions of a locomotive boiler requisite to furnish steam for any given number of horses' power; and, conversely, the evaporative power of boilers of given dimensions.

Locomotive boilers generally have been too small for the work they have had to perform: hence the tendency to work them at a speed and pressure greater than is safe to those around them. Considering the great extension of railways, and the observant habits of railway engineers, it is to be wished that some investigation of a more philosophical kind than the present were directed to this subject, and more especially by those whose connection with railways renders them more competent to the task. No one can be more conscious than the writer of the imperfection of the

* By R. Armstrong, C. E. (late of Manchester).

present step towards the opening up of such an investigation; but he trusts to the circumstance of its being a step in the right direction, and on ground entirely unoccupied by others, as some excuse for the attempt.

The boiler of the railway locomotive steam engine may be shortly defined as a 'cylindrical fire-box boiler,' with numerous small tubular flues, and 'direct draft' produced by discharging the 'exhaust' steam through the chimney. This definition is intended to point out, in a popular sense only, what would be the true position of the 'locomotive' amongst the numerous varieties of 'stationary' boilers, if taken from its carriage and set on brickwork.

In applying new methods of computation to such purely practical matters, it will be best to adopt the synthetical mode of giving, as we proceed, the rule and the reason for it at the same time,—trusting to some analogical experiments with stationary fire-box boilers, as a connecting link between the perfect stationary and the perfect locomotive boilers, to make our case complete.

2. The 'egg-ended' cylindrical boiler being the simplest and perhaps the best of all stationary high-pressure boilers, and easily appealed to in corroboration or correction of what we advance, almost every one being conversant with it, it will be best to take it as the groundwork for the data to be employed, assuming only, for our present purpose, that the plain cylindrical boiler with flat ends is in its evaporating power substantially the same. This is, in fact, identical with the common '*barrel boiler*' of the North of England Collieries; and when set up with a 'through draft,' or without side flues, or flues of any kind, as it frequently is, and with the furnace-grate at one end, of the same width as the boiler itself, it brings us one step nearer to the condition of the locomotive, and so far assists the comparison we are instituting.

3. Now it is not a mere matter of opinion, but the result of numerous experiments instituted upon a large scale *for practical purposes only*,—carried on under the inspection of the writer, and recorded in a work especially devoted to the subject of stationary boilers,—that the evaporative power of a boiler of this description, with a certain assignable amount of draft and quality of fuel, depends upon three points, which are as follow:

First. On the area of the fire-grate, or the area of the heating surface immediately over or very near it, exposed to the direct radiation of the heat from the burning fuel.

Secondly. On the whole area or extent of heating surface exposed to the upward action of the flame and hot air within a certain limit.

Thirdly. This limit is, that with a furnace-grate and bars of any ordinary construction, and common coal, there is no appreciable loss of evaporative effect, if the area of the effective heating surface only exceeds that of the fire-grate or radiant heating surface immediately over it, in the proportion of *nine* to *one*.

Although the above data for stationary boilers have direct relation to their evaporative powers alone, irrespective of their economy, experience has proved that the proportion of not more than 9 to 1, or a square yard of heating surface to a square foot of fire-bar, is also the most economical; and that by using fuel of a stronger heating quality, or by an increased draft, which amounts to nearly the same thing, even a somewhat less proportion of heating surface is sufficient to render any addition to it unadvisable in *any case*, as costing more than it is worth.

4. Applying the above proportions in practice, it was also found that there was no difficulty in evaporating a cubic foot of water per hour for each square foot of fire-grate, even with inferior coal; and that with the best coal, and careful management in feeding the fire, a proportion approaching to half a square foot was sufficient.

5. Taking the evaporation of a cubic foot of water per hour to be amply sufficient, as it is, for each horse-power in a common Boulton and Watt engine working unexpansively, the power (P) of any boiler to supply such engine with steam may be represented by

$$P = \tfrac{1}{2}(F + S),$$

where F = the area of fire-grate in square feet, and S = the effective area of heating surface in square yards, never greatly differing in amount from F, and never exceeding it. Where, however, S was considerably less than F, though not less than $\frac{1}{3}$ F,—below which our experiments did not extend,—instead of the arithmetical mean, we found the geometrical mean between F and S to express the nearest approximation to the greatest evaporative effect that could be produced, or

$$P = (F\,S)^{\frac{1}{2}}.$$

6. We will not assert that it is impossible to find a more correct expression for the relation that subsists between the areas of fire-grate and heating surface when a boiler is producing its maximum effect, than the above empirical formula presents; but it will not be easy to find one more eligible for ready application in practice.

The proportions of heating surface to the fire-grate above given being admitted as correct under the given circumstances of quality of fuel and draft, we may apply them in ascertaining the evaporative power of the boiler taken as our first example; namely,

7. *The cylindrical Boiler with flat ends.*—In order to obtain a simple expression for the heating surface of this boiler, in square yards, let L = length of the boiler in feet, D = the diameter, and $a = 3 \cdot 1416$; then, taking the lower half of the cylindrical boiler to be entirely exposed to the fire, flame, and hot air,—excluding the flat ends, which are generally compensated for by excluding from our measurement a few inches in depth of side surface, of about equal value, which is commonly covered over by the brickwork below the level of the central line of the boiler,—we have $\frac{1}{2}\,a\,D\,L$ = the area of the under surface of the boiler in square feet, and

$$S = \frac{1 \cdot 57\,D\,L}{9} = \frac{D\,L}{5 \cdot 7};$$

which, taking our previous data of a square yard of effective heating surface as sufficient for a horse-power, is also

$$P = \frac{D\,L}{5 \cdot 7}.$$

8. The cylindrical boiler under consideration may be supposed to have a diameter of 6 feet, which will conveniently admit a fire-grate under it of 5 feet square, = 25 square feet area; and in order to be arranged in the best proportions for a 25-horse boiler, as before indicated, would require a heating surface of 25 square yards, or

$$P\,(=25) = \frac{D\,(=6)\,L}{5 \cdot 7};$$

whence $L = \frac{5 \cdot 7\ P}{D} = 23 \cdot 75$ feet for the length of the boiler, which is nearly four times the diameter: but as it is expedient to approximate these examples as nearly as convenient to the more general proportions of the locomotive boiler, we may assume that 20 feet will be a preferable length in this case. Its heating surface will then be (Art. 7) $S = D\,L \div 5 \cdot 7 = 6 \times 20 \div 5 \cdot 7 = 20 \cdot 9$ square yards; which, being less than the number of square feet in the area of the fire-grate, the correct value of P is (by Art. 5) $= (F\,S)^{\frac{1}{2}} = \sqrt{25 \times 21} = 23$ horse-power nearly.

9. In pursuance of this investigation, it may now be supposed that for the purpose of increasing the heating surface and consequent economy of this boiler, and for diminishing the quantity of water it contains, in order to bring it nearer the condition of a locomotive, it is determined to put into it a cylindrical flue of 4 feet diameter, passing longitudinally through it from end to end. Supposing also that the fire-grate remains as before, but that instead of the smoke passing direct from below the boiler into the chimney it takes one turn through the inside flue, let us examine the amount and the effect of the additional heating surface which is thus obtained.

10. It has been found by repeated experiments with common square or nearly rectangular-sectioned flues, that the top of the flue only is fully effective in generating steam; the sides, if nearly vertical, having very little effect, and the bottom of the flue still less, or next to none; and that in a circular flue, whatever effect may be due to the bottom and sides, it is amply compensated for by allowing the upper semi-cylindrical portion to be calculated to the full extent of its area as effective heating surface. And when we consider that the smoke and hot air must act against the *inside* or upper concave surface of the flue, in the same manner as they would do against the *outside* or lower convex surface, supposing the flue to be taken out and fixed up as an extension of the boiler, it is evident that the effective heating surface of the flue cannot be reckoned at less than we have stated: therefore, in computing the effective heating surface of all circular flues, the lower half must be entirely excluded as non-effective.

11. From the above considerations it appears, that the expression for the effective heating surface of the outer shell of the boiler must also be the correct one for that of the inside flue, or $S = DL \div 5{\cdot}7 = 4 \times 20 \div 5{\cdot}7 = 14$ square yards, which, added to the heating surface of the shell, $= 21$ square yards, as before found, gives 35 yards as the total effective heating surface of the boiler and flue. Such a large additional surface would enable the boiler to produce the full evaporative effect due to its 25-horse fire-grate; and such a boiler for *evaporating purposes only* (though not for working a *stationary* engine) we know from experience to be extremely economical of fuel.

12. The most obvious way that now presents itself to assimilate the condition of this boiler towards that of a locomotive, is to remove the furnace from under the boiler, and to place one with a fire-grate of the same area within the inside flue. This done, the evaporative power and economy of the boiler will remain just the same as before, provided the hot air is compelled to return down and spread itself under the boiler bottom before passing into the chimney. If, however, we discard all the effect to be obtained from applying heat to the external surface, and allow the smoke to pass direct from the inside flue to the chimney, we acquire a still nearer approach to the locomotive principle, and our hypothetical boiler at once becomes the *Trevithick locomotive boiler*, the great forerunner of Stephenson's.

It is certainly true that these proportions of 25 square feet of fire to 14 square yards of surface, making a boiler, according to our views, of $\sqrt{25 \times 14} = 18\frac{1}{2}$ horse-power, would be far from economical. But it only requires to have a 14-horse furnace-grate to make it a good 14-horse boiler for various evaporating purposes; and with a steam dome and a fire-feeding machine it would be equally good as a steam *engine* boiler.

13. The first improvement that suggests itself in the last-named boiler is to take out the large flue and to substitute two smaller ones instead, each of $2\frac{1}{2}$ feet diameter, thus increasing the effective heating surface to ($2\frac{1}{2} \times 2 \times 20 \div 5{\cdot}7 =$) $17\frac{1}{2}$ square yards. This, with a fire-grate in each flue corresponding to the heating surface, would make a good $17\frac{1}{2}$-horse boiler, not very dissimilar in proportions to some of the oldest locomotives.

14. Another variation or extension of the principle of the above '*double-furnaced*' boiler would be its conversion to the condition of the '*circular marine boiler*,' by having the two furnace or main flues made something less in diameter, say 2 feet, so as to allow them to be placed lower down in the boiler for the purpose of admitting four smaller flues, each of 12 inches diameter, returning from the smoke-box over the top of the former to the chimney. The effective heating surface in this case is again increased to 28 square yards, making, with an adequate area of fire-grate, a boiler of about 28 horse-power.

15. The next point of view in which to place our hypothetical boiler, in its approximation to the locomotive, would be that of a kind called the '*Liverpool Patent*' construction, which became suddenly very popular soon after the opening of the Liverpool and Manchester Railway: they were precisely the same as the last mentioned, or 'circular marine boiler,' only that they were adapted for land purposes, and a fire-box was added. Many of them were made about the time referred to, but they generally failed for want of draft. They were as nearly as possible the same as those called '*Stevens's American Boilers*,' of which some valuable details were given in Mr. Weale's 'Engineer's and Contractor's Pocket Book' for 1848; from which it also appears that to America belongs the honour of first applying them successfully in steam boats, in conjunction with the fan-blast and anthracite coal. Not, however, being in possession of their actual evaporative power in practice, we here give the dimensions of one of a very similar kind, many of which came under our own observation in Lancashire, in 1833, certainly some years antecedent to their re-invention in America.

16. This was a *seven-flued fire-box boiler*, 23 feet long in the cylindrical part by 7 feet diameter, with the addition of the fire-box of 7 feet wide externally by $7\frac{1}{2}$ feet long, making a total length of $30\frac{1}{2}$ feet: the internal fire-box was $6\frac{1}{2}$ feet wide by 7 feet long and 4 feet deep. Of the seven flues three were direct, averaging 13 inches diameter by 21 feet long, passing from the fire-box to an internal 'take-up,' or smoke-box: from this smoke-box proceeded four return flues, each of 12 inches diameter by 28 feet long, passing over the top of the other three flues, and over the top of the fire-box to the front of the boiler, where the smoke passed out to the chimney, after making one turn under the cylindrical part of the boiler. Two of these boilers were worked for some years at a chimney with a good draft (equalling a pressure of half an inch of water), evaporating from 40 to 50 cubic feet of water per hour with only a moderate consumption of fuel; which was a greatly improved result compared to that obtained from some others, by the same makers, with a greater number of smaller flues, and consequently worse draft.

17. Reverting to our hypothetical boiler of 20 feet by 6, we shall, by putting into it a dozen direct tube flues, each of 9 inches diameter, and adding a fire-box of 6 feet by 5, again increase its heating surface, while the collective cross sectional area of all the tubes is nearly doubled; therefore, with the same chimney or blast, we know that the draft would not be diminished.

The effective evaporating surface of the flues alone, or $\text{S} = \text{D}\,(= \cdot 75 \times 12 = 9 \text{ ft.}) \times \text{L}\,(=20) \div 5 \cdot 7 = 31$ square yards, with a fire-grate of 30 square feet in the fire-box, may be considered a good 30-horse boiler.

18. Having proceeded so far to shew the increasing capabilities of the locomotive boiler, considered as an evaporating instrument merely, in its gradual conversion from the simple cylindrical stationary boiler to the direct-draft locomotive boiler of Trevithick, and through various forms of construction, to the multiflue or 'tubular fire-box boiler of Stephenson,—computing the power derivable from each alteration, and tracing their nearest analogies to stationary and marine boilers, as grounds for

such computation, we now introduce another element into the calculation, namely, the *radiant heating surface of the fire-box.*

19. In calculating the power of stationary boilers, we have always considered the radiant heating surface as nearly co-extensive with the area of the fire-grate, and therefore the expression for them in any formula for the power as nearly the same: where, however, the area of the fire-grate is small in comparison with the depth of the fire-box, as in a locomotive, the case is very different; for instead of that part of the heating surface in the furnace which is very near the fire being immediately over the latter, as in a common boiler, the sides of the fire-box are, on the contrary, mostly vertical, whilst the part which is horizontally over the fire, namely, the top of the fire-box, is really the furthest off. Now the evaporative value of different portions of this surface must depend in some measure on adventitious circumstances, which will vary a little in different cases, such as the direction given to the current of air through the grate; though Engineers have generally agreed with Pambour in treating it as if it were uniform in its heating effects, calling all the surface exposed to the direct radiation from the burning fuel on the grate, indifferently, '*radiant heating surface;*' whilst the total surface of the tubes or flues, exposed only to the hot air or smoke, has been called '*communicative heating surface.*' As to the communicative surface of the tubes, we have already considered one-half of it only to be really effective in generating steam (Art. 10), for reasons which will presently appear.

20. If we take a square iron box immersed in water, and keep it continually filled with a current of hot air passing through it, in sufficient quantity to keep the water gently boiling, we find that the upper surface, when horizontal, generates more than double the quantity of steam per unit of area generated by the sides, when the latter are vertical,—whilst the bottom generates none at all. These facts are evidently quite independent of the action of the hot air on the internal surface of the metallic box, which of course is uniform, and arise entirely from the difficulty there is in the water getting proper access to, or coming into close contact with, the side surface (except at a small portion towards the bottom), so as to take the heat up with sufficient facility to become converted into steam. The minute bubbles of steam, as they rise more or less rapidly to the surface of the water, constitute, in fact, the condition of *boiling*, or generating steam, as distinguished from *simmering*, or merely heating the water preparatory to boiling. And whilst this steam thus rises freely and unobstructed, and therefore rapidly, from the top of the box, that generated near the bottom or lower portion of the sides, in rising vertically upwards (which it must do generally), is compelled to pass between the surface of the heated iron plate and the water, forming a thin current or stratum, as it may be called, of steam, which by its constant interposition completely prevents the proper access of the water to the heating surface with sufficient rapidity for effective evaporation.

A strong illustration of the above general fact is afforded by inclining the heated box a little sideways, so that one of the sides may incline a very few degrees from the vertical upwards, whilst the opposite side declines at the same small angle from the vertical downwards, when the very great difference in the amount of evaporation becomes strikingly apparent,—the bubbles of steam, as they are formed, rising rapidly from the elevated side, whilst they hang sluggishly against the opposite one, and appear only to be driven off at last by actually *overheating* and injuring the plate.*

21. It is, moreover, evident that there must be a different evaporative value for

* This injury to boiler plates inclined in a wrong position is not so conspicuous in the *copper* fire-box of a locomotive as in the *iron* fire-place of a marine boiler.

every alteration of the angle of inclination of the generating surface; as a variation of 2 or 3 degrees makes a sensible difference in the amount of evaporation from the sides, whilst any difference in the effect produced by the top is not to be perceived even when inclined as much as 20 or 30 degrees from the horizontal. Sufficient, however, for our present purpose is the knowledge of the fact now generally admitted, that the evaporative value of the top surfaces of fire-boxes and flues, even when inclined as much as 45 degrees from the horizontal position, is to that of the vertical or very nearly vertical surface, as about *two* to *one*.

22. Hence arises a very obvious and ready rule for the practical measurement of the effective surface of all kinds of flues and fire-boxes. It is as follows: When the area of side surface does not exceed that of the top surface in any unit of the length of the flue, take them together as effective surface, which agrees with the rule already given in respect of circular flues (Art. 10); but when the side surface exceeds the top surface, then take half of such excess, and adding it to twice the area of top surface, call the combined amount the effective heating surface.

It may here be observed, that in several trials with stationary fire-box boilers, using coals, the evaporation produced by each square foot of effective *radiant* surface, measured in the above way, together with a proportional area of communicative surface, was found to be accurately equivalent to that produced by the same area of fire-grate and heating surface in a common waggon boiler, a corresponding consumption of fuel being required in each case.

23. From the above it will appear that there is no need to make any reference to the area of the fire-grate in any calculation of the power of a fire-box boiler, so long as an equal consumption of fuel is effected by a greater or less rate of combustion or otherwise.

Agreeably, then, to these conclusions, we may take each square foot of effective radiant heating surface in the furnace of a fire-box boiler to be sufficient for each horse-power when common coals and the ordinary draft are used. And supposing the normal working condition of the boiler of a locomotive to be that in which little or no power is lost by the contraction of the blast pipe,—or when the exhaustion of the chimney by the simple discharge of the eduction steam causes an average draft through the furnace equal to that which is produced by a good chimney for a stationary engine, or equal to the pressure of half an inch of water,—the cases are sufficiently analogous to authorise us to use the same method of computation in both.

24. Equations for the heating surface and horse-power of locomotive engine boilers corresponding to those already given (Arts. 7, 8) for stationary boilers are as follow:

$$S = \frac{d\,L}{5\cdot 7}, \text{ also } P = c\sqrt{R\,S},$$

where d = the collective diameters of all the tubes in feet; L = the length of the tubes or of the cylindrical part of the boiler in feet; S = the effective *communicative* heating surface of all the tubes in square yards, never being less than 1; R = the effective *radiant* heating surface of the fire-box in square feet, which should not be less than S: where, however, R is less than S, the equation for the power P is simply $P = c\,R$; the co-efficient c depending on the combined effect of the blast and the quality of the coke, to be determined by experiment, but which in the normal state of the locomotive may be considered equal to unity.

25. The problem now is to determine from some actual case the value of c when a locomotive is exerting its maximum effect; for which purpose we may take as an

example Mr. Stephenson's patent six-wheeled engine, as given in the last edition of Tredgold on the Steam Engine.

It contains 124 tubes, each of $1\frac{5}{8}$ inch diameter and 7 feet 9 inches long. Hence $d = (1\frac{5}{8} =)\ 1{\cdot}625 \times 124 \div 12 = 16{\cdot}79$ feet, = the collective diameters of all the tubes, and $S = 16{\cdot}79 \times 7{\cdot}75 \div 5{\cdot}7 = 22{\cdot}8$ square yards, = the *effective* area of tube surface.

The total area of the internal surface of the fire-box is 50 square feet, the top being about $10\frac{1}{2}$ and the side surface $39\frac{1}{2}$; therefore $39\frac{1}{2} - 10\frac{1}{2} = 29$, is the excess of the side over the top surface, of which, according to the rule given in Art. 22, we take half $= 14\frac{1}{2}$, and adding it to twice the area of the top, we have $R = 14\frac{1}{2} + (2 \times 10\frac{1}{2}) = 35\frac{1}{2}$ square feet for the *effective* radiant surface of the fire-box; and

$$P = c\sqrt{35{\cdot}5 \times 22{\cdot}8} = 28{\cdot}4\,c.$$

Now it appears from Mr. Stephenson's account of this engine, that the extent of its power, with steam at the pressure of 50 lbs. per square inch in the boiler, was about 77 horse-power, the boiler then evaporating 77 cubic feet of water per hour by 8 lbs. of coke for each cubic foot. Whence $c = 77 \div 28{\cdot}4 = 2{\cdot}7$, which gives

$$P = 2{\cdot}7\ \sqrt{RS}$$

for the horse-power of any locomotive engine boiler on this principle.

26. We will now give practical examples of the converse of the above operation, by which to find the dimensions of a locomotive boiler for a given power; and as the tendency for some years past has been to increased speed and higher pressure, consequently giving greater power under the same dimensions, we shall only err on the right side by adopting 3 as a round number, instead of $2{\cdot}7$, for the co-efficient in the expression for the horse-power of this engine; whilst it is certain that the progress of improvement must eventually extend the value of c to 4, —5, or even to 6.

Example 1.—Required the dimensions of the tubes and fire-box of a locomotive boiler of 78 horse-power?

The first thing is to fix upon as large a fire-grate and horizontal area of fire-box as the gauge of the rails will permit, which we may suppose to be the same as in the last example, $= 10\frac{1}{2}$ square feet, which will also be the area of the top surface of the fire-box. Now we want as many square feet of *effective* radiant surface in the fire-box as is equal to the given power divided by the co-efficient 3, or $78 \div 3 = 26$; and this 26 feet (= R) must be made up as follows :—

	Square feet of effective surface.		Square feet of side surface.
Double the top surface $= 10\frac{1}{2} \times 2$ . . .	= 21	containing . .	$10\frac{1}{2}$
Half the remaining side surface to make up 26 =	5	requiring . .	10
	26		$20\frac{1}{2}$

And the total heating surface of the fire-box will therefore consist of $20\frac{1}{2}$ square feet of side added to $10\frac{1}{2}$ of top surface, = 31 square feet, of which only 26 is considered effective.

Then we have only to take a corresponding number of square yards (= 26) of effective tube surface to complete the boiler. This may be done variously; but supposing it to be distributed amongst 124 tubes of $1\frac{5}{8}$ inch diameter $= 16{\cdot}79$ feet, collectively $= d$; and since $S = 26 = \frac{d\,L}{5{\cdot}7}$, therefore $L = \frac{5{\cdot}7\,S}{d} = \frac{5{\cdot}7 \times 26}{16{\cdot}79} = 8{\cdot}8$ feet will be the length of the tubes which will regulate the length of the cylindrical part of the boiler.

27. Should it be considered that economy of fuel is not required to be carried to so great an extent as the length of tube found in the above example would seem to indicate, or that a less proportion of tube to fire-box surface than 9 to 1 is sufficient, —and that for this or for any other reason the length of tube adopted in Mr. Stephenson's engine is preferred, namely, 7 feet 9 inches instead of 8 feet 9 inches,—we shall now see how much additional surface will be required in the fire-box, in order to admit of the tubes (and consequently the boiler) thus being made one foot shorter without any loss of power.

Example 2.—Required the dimensions of the fire-box of a locomotive engine of 78 horse-power, the length of the tubes being fixed at 7 feet 9 inches?

Here, as in the last example, it may be granted that the number of tubes (=124) and their diameter ($1\frac{5}{8}$ inch) are also fixed,—because, in fact, they require to be determined from entirely different considerations, namely, *weight* and *strength* of the parts, subjects that could not be entered upon within the limits of this article, involving as they do those of collisions and explosions.

We have $d = 16{\cdot}79$ feet = the collective diameters of all the tubes, as before; and $S = \dfrac{16{\cdot}79 \times 7{\cdot}75}{5{\cdot}7} = 22{\cdot}8$ square yards, the same as in the first example, which with a fire-box containing a corresponding number of square feet of effective radiant surface, or $R = 22{\cdot}8$, would only make the boiler equal to $22{\cdot}8 \times 3 = 68{\cdot}4$ (= P) horse-power.

But we require the value of R when P = 78.

Therefore (by Art. 24) we have $P = c\,\sqrt{RS}$.

Whence $R = \dfrac{\frac{1}{3}P^2}{S} = 26^2 \div 22{\cdot}8 = 29{\cdot}6$ square feet for the effective radiant surface of the fire-box.

Arranging this precisely in the same manner as in the last example,—

	Square feet of effective surface.		Square feet of side surface.
Double the top surface $10\frac{1}{2} \times 2$	= 21	containing .	10·5
Half the remaining side surface to make up 29·6 =	8·6	requiring .	17·2
	29·6		27·7

Hence it appears that the total area of the internal surface of the fire-box consists of 27·7 square feet of side surface + $10\frac{1}{2}$ of top surface, making 38·2 square feet, of which only 29·6, or 77 per cent., is really effective.

And taking the average perimeter of the radiant surface at 12 feet, it gives $27{\cdot}7 \div 12 = 2{\cdot}3$ feet for the effective depth of the internal fire-box.

28. The most direct rules in words, derived from a consideration of the foregoing and simplified as much as possible, are as follow:—

Rule 1.—*To find the dimensions of the fire-box.*—Take one-third of the given horse-power for the effective radiant surface in square feet, calling it R, and also one-fourth of R for the top surface of the fire-box: then take five times the top surface for the side surface, which, divided by the horizontal perimeter, gives the depth of the fire-box.

Rule 2.—*To find the effective tube surface and length of boiler.*—Take one-third of the given horse power for the effective communicative heating surface in square yards, calling it S. Multiply S by 5·7, which gives the longitudinal sectional area of all the tubes in square feet; and this area, divided by the collective diameters of all the tubes in feet, gives the length of the tubes, and the length of the cylindrical part of the boiler is nearly the same.

Rule 3..—*To find the horse-power of a locomotive boiler.*—Multiply the number of square feet of effective *radiant* heating surface in the fire-box by the number of square yards of effective *communicative* heating surface in the tubes (this number not being greater than the former nor less than 1), and extract the square root of the product: this root, multiplied by the constant number 3, will give the horse-power of the boiler required.

29. Knowing the wide extension of a little practical knowledge of such matters amongst the great mass of our operative engineers to be of more importance than greater refinements of calculation confined to a few, the principal rules given above are converted to a shape suitable for the slide-rule, especially for their use; but it should be observed, that when Hawthorn's slide-rule is used, the slider requires to be reversed as follows:

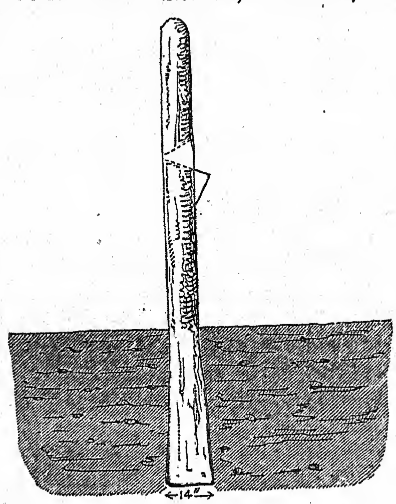
No. 1.

A	Diameters of *all* the tubes in feet $= d$.	$5 \cdot 7 =$ constant number or gauge point.
D	Length of each tube in feet . $= L$.	$S =$ effective tube surface in square yards.

No. 2.

A	$\frac{1}{3}$ the horse-power P.	$R =$ fire-box surface in square feet.
D	$\frac{1}{3}$ the horse-power P.	$S =$ tube surface in square yards.

STOCKADE.—*Stockade*, or *Stoccade*, is the name given to a close barricade of timber, for intrenchments or redoubts. The Pah of the New Zealanders, and Palanque of the Turks are examples of closed stockades: and the drawings to the article 'Petard' give several forms of construction. The barricade may be either of square timber, musket-proof, or of trees with two sides smoothed off with an axe, to make them meet, having small loopholes cut at the junction; and the stockade ought to be so strong as to resist being forced, except by artillery or by bags of gunpowder. This last mode of destruction may be prevented by giving the stockade proper musketry flank defence. To make this species of barricade secure, the timber should be sunk into the ground one-third of its whole length.



Stockade for Intrenchment.

One objection to stockades for intrenching posts and fortified places is their liability to destruction by artillery before they are required: this might be obviated in permanent works as regards the intrenchment of the *re-entering place of arms* of the covert way or ravelin, or *gorge of a work*, by having narrow ditches or dykes, 12 or 14 inches wide and 4 feet deep, previously prepared in masonry, and covered over with slabs of stone until wanted. When an assault was apprehended, the timber for a stockade, kept on purpose in store, might be let into these crevices, and well wedged together,—a work, thus prepared, of a few hours, as explained in the preceding diagram. G. G. L.

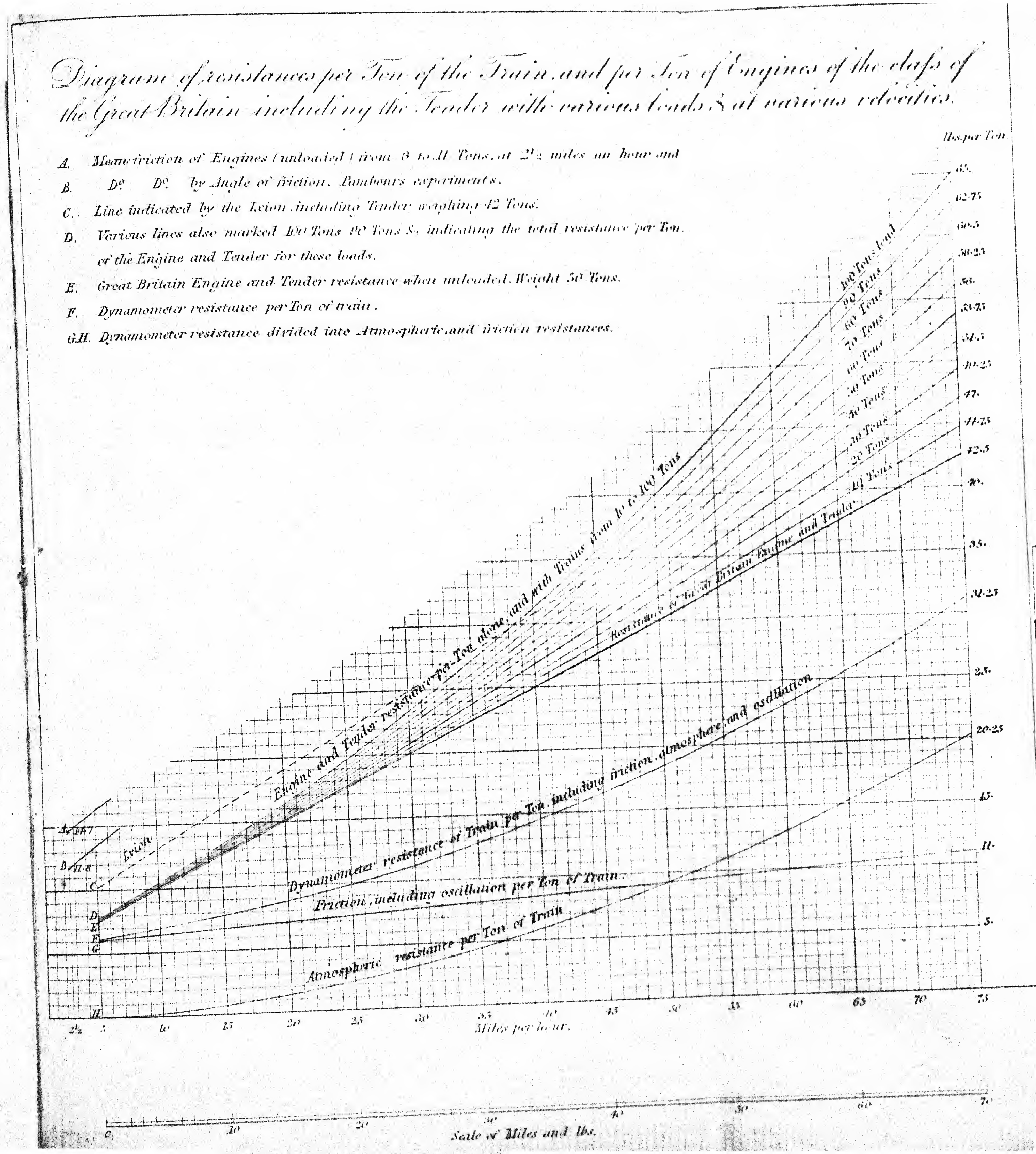


Diagram of resistances per Ton of the Train, and per Ton of Engines of the class of the Great Britain including the Tender with various loads & at various velocities.
lbs per Ton
A. Mean friction of Engines (unloaded) from 8 to 11 Tons, at 2½ miles an hour and
B. D°. D°. by Angle of friction. Pambours experiments.
C. Line indicated by the Ixion, including Tender weighing 42 Tons.
D. Various lines also marked 100 Tons 90 Tons &c indicating the total resistance per Ton. of the Engine and Tender for these loads.
E. Great Britain Engine and Tender resistance when unloaded. Weight 50 Tons.
F. Dynamometer resistance per Ton of train.
G.H. Dynamometer resistance divided into Atmospheric and friction resistances.
100 Tons load
90 Tons
80 Tons
70 Tons
60 Tons
50 Tons
40 Tons
30 Tons
20 Tons
10 Tons
Engine and Tender resistance per Ton alone and with Trains from 10 to 100 Tons
Resistance of Great Britain Engine and Tender
Ixion
Dynamometer resistance of Train per Ton including friction, atmosphere and oscillation
Friction, including oscillation per Ton of Train
Atmospheric resistance per Ton of Train
Miles per hour.
Scale of Miles and lbs.

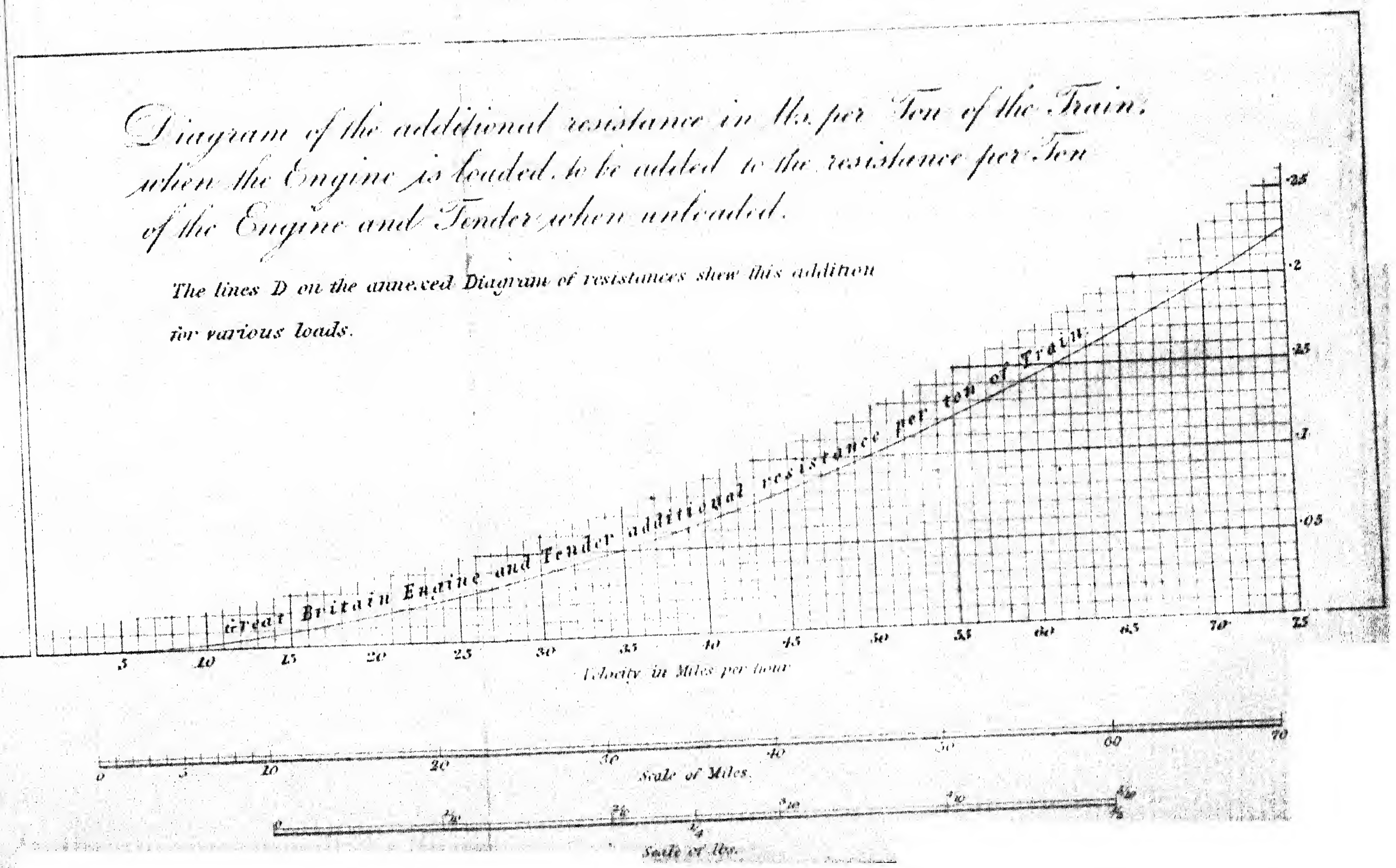


Diagram of the additional resistance in lbs. per Ton of the Train, when the Engine is loaded, to be added to the resistance per Ton of the Engine and Tender when unloaded.
The lines D on the annexed Diagram of resistances show this addition for various loads.
Great Britain Engine and Tender additional resistance per ton of Train.
Velocity in Miles per hour
Scale of Miles.
Scale of lbs.

STREET FIGHTING.*

ON THE ATTACK AND DEFENCE OF OPEN TOWNS, AND STREET FIGHTING.

Notwithstanding the very frequent success attending the defence of towns or streets by armed bodies, against even considerable forces of good troops, and the tremendous results occasionally arising from such resistance, no attempt seems to have ever hitherto been made to analyze the actual relative power of the two parties attacking and defending, or to ascertain whether the advantages so often gained by the latter are precisely due to their real power, or might not be counteracted under proper principles adopted for the attack.

In an enemy's country the case is much simplified: a town so occupied is all inimical and under the most desperate state of opposition; consequently in the attack there is no respect to person or property. If the houses are combustible, a ready means of subduing the place is within reach; and if not, it is forced in different directions by siege operations, as practised by the French at Saragossa.

On occasion of internal dissensions and insurrectionary movements, the case is different; the efforts of the troops and of the well-disposed citizens are greatly impeded by the difficulty of distinguishing between friend and foe, or of the premises or property with which it may be justifiable to interfere. This, and the very natural and proper anxiety to avoid bloodshed and injury to one's own countrymen, frequently leads to a habit of temporizing with the circumstances, and by this indication of timidity and weakness gives such confidence to the rebels as to enable them, and perhaps with comparatively insignificant numbers, to gain in moral effect as the others lose: by degrees the wavering and the timid are led to join them; the troops themselves imagine that there is a declared power manifested that is not to be opposed, and thus the former obtain a complete ascendancy, which the exertion of more firmness and system at first would effectually have prevented.

The most arduous and difficult task for a British soldier is, when he is called upon to oppose tumults and insurrection. It is difficult for him and his Commanding Officer to know what is the extent of evil, provocation, or injury that will justify him in acting with vigour; and this feeling is increased by finding women, children, and many men who do not appear to participate in the violence, mixed up with his opponents, until by degrees he becomes surrounded and overcome by a mass which he could readily have subdued if allowed to act at the commencement; or even if not subjected to so great a disaster, by this temporizing in the first instance the movement gains a great deal, the troops in force are obliged to act with determination, and a vast number of lives are lost that would have been spared by a more early exertion of energy.

The best institutions of any country become endangered by such a state of things; but a remedy may be found in a more systematic manner of proceeding.

The troops should never be brought into the presence of the insurrectionists until fully authorized to act,—the consequence would be that the very appearance of the soldiers would be a warning to every one of the immediate consequences of prolonged opposition, which would prevent further conflict, or make it very short.

The strength and organization of the police in all large towns in England now will enable this principle to be adopted, while it could hardly have been done formerly.

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* By General Sir John F. Burgoyne, Bart., G. C. B. and R. E.

When the magistrates find that the efforts of the police are insufficient to establish order, the Riot Act should be read, and the troops then, and not till then, be brought into action: they would thus be aware of their authority to proceed without hesitation, and with decision and effect.

In order to promote the power of vigorous action by the military, and to prevent the innocent from suffering, the most solemn warning should be issued in case of tumult, against the presence in the streets of women, children, and persons who do not join in the troubles, intimating that the consequences of any bad result from their being thus incautiously exposed must rest on themselves. These are necessary preliminaries to the consideration of the means of attacking an insurrectionary force.

When disturbances are to be quelled in a town, cavalry, artillery, and infantry can act with full effect, and with every advantage of organization, so long as their opponents occupy the open streets. If barricades are constructed across them, the cavalry become unserviceable; the infantry, however, have still full force,—for one side of an ordinary barricade is as good as the other,—and the infantry can cross any of them without difficulty.

But when, in addition to barricades, the armed populace occupy the houses, and fire and throw down missiles on the troops, the columns of the infantry also become paralyzed and comparatively helpless, and after losing many men, they have usually been repulsed;—a discomfiture arising more from a want of system and of due preparation against such a defence, than from the inherent power of the insurgents.

Should the circumstances as above described impede the operation of cavalry or infantry, they should be respectively withdrawn from the direct attack, care being taken that this should not give any impression of *defeat*, which may be done by preparing the mind of the soldier, through instructions to the Officers, that such would be the course of proceeding.

When it is found that the insurgents have had recourse to the most determined means of resistance, by occupying the interior of houses in support of barricades, the mode of attack must be adapted to the circumstances.

The operation should be conducted under due deliberation, nor would any triumph be conceded by a moderate pause.

It will be readily ascertained what part or parts of the town are so occupied as to render the movement of the troops through the open streets unadvisable.

An endeavour should be made to isolate those portions by detachments of troops posted at all the approaches to them. This of itself would throw the rioters into a most uncomfortable and false position: they would find themselves shut up without any internal organization to enable them to act to any useful purpose, or to make any combined forcible effort for their release;—or, indeed, if they could do so, it would have all the effect of *an escape* instead of a victory.

Nor would it be necessary, under such circumstances, that these detachments should be at all large, numbers of them being supported by some general reserve.*

Active measures, however, might at the same time be carried on against any portions of the houses that it may be considered advisable to force, for the purpose of confining the resistance within narrower limits, or for subduing it at once altogether

* At Berlin, General Schreckenstein, in answer to a deputation who came to remonstrate against his proceedings to oppose the popular demonstrations, is said to have stated, that he would tell them candidly, that in the event of tumult or attempt to subvert existing institutions, his plan was to withdraw every soldier from the town, invest the gates, patrol round the walls, shut them up within, and leave them to enjoy the effects of their misule and misconduct; that he would not compromise a single life by street combat; but if a man among them showed himself armed outside, that he might beware of the consequences.

and these should be conducted on engineering principles, and by Officers of Engineers and Sappers, where they are available.

Although in towns the attack of a mass of houses is formidable and almost impracticable to troops unprepared for such an operation, it will not present much difficulty to a systematic proceeding.

One great defect for defence in a house or street is its want of a flanking fire, although every part may obtain a support from the opposite houses in the same street. If therefore only one side of the street is occupied, individuals or parties moving close along that side are in security, except from the chance missiles that may be blindly thrown down from the windows.

Nothing of that kind could prevent two or three Sappers, under cover of a partial fire on the windows, from passing up and breaking open the doors; by which means, the troops being admitted, possession of the entire building would soon be obtained.

When, however, from any peculiarity of the building, or of others contiguous, or from the circumstance of both sides of the street being occupied in force, such a mode of proceeding would be too hazardous, the Sappers might make an entrance into the nearest available house in the same block of buildings, and, supported by detachments of the Line, work their way through the partition walls, from one house to another; or by the roofs of the back premises, where the defenders will be quite unprepared to oppose them, or, if they made the attempt, would not have the same advantages as in front: small parties, if necessary, keeping up a fire on the windows from the walls of the back yards, or from the opposite houses, would effectually cover these advances of the Sappers.

To carry on such approaches, the Sappers should be provided with an assortment of crowbars, sledge-hammers, short ladders, and, above all, some bags of powder.*

In these desultory operations in the defiles of streets and houses, the troops should not be in heavy columns, but in small detachments well supported; and by acting thus in order, and on system, the effect will be the more certain, as a popular movement is, necessarily, without subordination or unity of action, and peculiarly subject to panics at any proceeding differing from what had been anticipated.

The events in Paris, in June, 1848, and the mode adopted for the attacks on the barricades there, by an army of acknowledged skill and prowess, would seem to oppose the soundness of the principles here laid down: we cannot, however, abandon them, but must suppose either that the Generals, under too great a contempt of their opponents, acted upon the old impetuous system of a direct assault, on what, under the circumstances, were well-devised and most formidable retrenchments,—from not taking the trouble to consider whether a more judicious professional proceeding, and more certain in its result, might not have been adopted,—or were impelled by other causes with which we are not acquainted; for it appears almost incredible that an immense force of organized troops, even *numerically* superior to the insurrectionists, should have, for some days, to carry on a contest against them, with almost doubtful success, and attended with such prodigious losses.

We are consequently, by this very example, rather the more inclined to maintain that in the attack of streets defended by good and well-supported barricades, it is most injudicious and dangerous thus to take the bull by the horns.

The defence of towns, either without fortifications, or independent of them, is

* Not less than 5 or 6 lbs. of powder will be required to break into strong doors well barred.

usually only undertaken by a population, or by troops essentially irregulars, in order to make up by numbers, and the intricacies of position, for the disadvantage of inferiority in arms, appointments, and organization, which renders them unequal to cope with their enemy in the open field.

It is seldom that effective troops can be spared for this service ; but officers, and especially officers of Engineers, may be required to regulate such a defence.

When an enemy's army is in a country, it will hardly be practicable to defend against it with any obstinacy a town the houses of which are combustible,—the attempt in such a case would be to occupy only some particularly strong public buildings or churches, when circumstances may shew it to be advantageous to do so, in order to command a bridge, or defile, or to occupy some distinct point.

The object then, however, partakes of the nature of the defence of single posts, and not of streets, or of a town generally.

When towns consist of strong-built large stone houses, with massive doors, and iron bars covering the lower windows, as are common in the South of Europe and some other countries, they are capable of great defence : traverses may be thrown across the streets, flanked by the houses; all openings to the front may be substantially barricaded, loopholes prepared in the most appropriate situations, and communications made through the premises in the rear for support or retreat : care being at the same time taken that this general defence cannot be turned,—it is only to be overcome by breaching, and more or less of a siege operation.

The strength of such a resource, however, is not limited only to that of the single covering above described ; but the preparations may embrace the successive defence of house after house, or at least be so arranged that every line penetrated shall give the attacking party possession only of a certain given small portion of the town, leaving them not only the same difficulties to overcome in front, but perhaps also a continued occupation on their flanks.

This was the manner in which the Spanish forces under Palafox, in 1808 and 1809, incompetent to resist in the field the superiorly organized French army, were enabled, combined with the population, to make such a prolonged defence in Saragossa after the fortifications had been reduced.

A striking instance of the advantages that may be derived from the preparation of houses in streets in such towns, is afforded in the defence of Tarifa by the British in December, 1811. A week or ten days were sufficient for the French to lodge themselves within a few hundred yards of the place, and to open a practicable breach in the old wall, which was the only cover. During that time, however, the late Lieut.-General Sir C. F. Smith, then Commanding Engineer, was enabled rapidly to form an interior hold or intrenchment by barricading the streets, closing all accessible openings of the houses to the front, and preparing loopholes in the most advantageous places, so that he could state emphatically that the place was then stronger than before it was breached ; and his confidence was proved to be so far well judged, that the storming parties were completely repulsed, and the siege raised.

These, however, are the proceedings of regular troops, conducted under all the principles of the Art of War ; the considerations for the attack and defence are essentially to be founded on those which regulate sieges and the defence of fortresses.

Lodgments must be made, and the further progress will be effected by the mine and other operations, which it is not the intention to describe in this article.

There is, however, a consideration to be given to the necessity for the defence of towns, or premises within them, arising from the effects of popular tumults or insurrectionary movements, totally distinct from the above.

Very great results have been produced from such affairs, which, notwithstanding

their importance, have, in many instances, it is submitted, been conducted with great want of judgment.

It becomes, therefore, a subject of interest to consider what principles can be applied to proceedings of this nature.

It is not the part of any officer of Her Majesty's Service to offer suggestions or instructions that would guide insurrectionists as to the best mode of occupying and making use of streets and houses to resist the constituted authorities.

We pass, therefore, in our consideration of the subject of defence, to the objects for which a government will itself require protection from mobs or insurgents.

These will consist of the public offices, palaces, and great leading establishments, liable to attack, either for the purpose of embarrassing the government or for plunder as well as any particular posts of defensive military importance, such as bridges, or other points affording the command of great communications.

The leading principles to be adopted for the protection of these premises will be,—

I. To insulate them, or such masses of them as are to be held, as much as possible from connection with other buildings.

Where this cannot be entirely accomplished, means must be prepared for securing an entry, and for turning the rebels at once out of such adjoining buildings as they may attempt to occupy for the purpose of annoyance, and if they afford any advantages, to connect them with the defence of the main buildings.

Premises that are not absolutely contiguous may present windows or roofs capable of greatly annoying the defence: means must be especially prepared, if possible, for driving out any adverse force that might occupy them; but if that cannot be done, in consequence of the difficulty of penetrating through the intervening space, or from any other reason, the prepared cover and protection must be adapted to reduce that inconvenience as much as possible.

II. Block up substantially all accessible openings from the streets that may not be immediately required, and apply musket-proof doors to those that must be maintained available; and if there may be a selection, let these be in parts where the approach to them is most exposed to fire from the building.

III. All windows within tolerably easy reach of the ground to be secured by strong fixed iron bars or gratings.

IV. Wherever the parties within are required to be stationed for the defence, they should be covered by some substance to act as a breastwork, that will resist musket-shot, having merely loopholes before them for their own use.

This cover will only require to be to a height of 5 feet 10 inches or 6 feet above the floor on which they stand, consequently hardly so high as the top of the lower sash of an ordinary window.

Where this may not have been prepared, and it is necessary to resort to a hasty defence, the upper floor of the building may be occupied, loopholing the floors, and barricading the staircase with chairs, tables, &c. At the sortie of the French at Bayonne, in 1819, a Captain Foster with a few men occupied the upper floor of a house at the advanced post, and defended themselves against repeated attacks until the sortie was over, when they were relieved.

Even a blind or curtain drawn before a window is of service, as the assailants cannot see when there is any one behind it, by which to be guided when and where to direct their fire, while those within can take their shots from time to time, and instantly retire.

On the floors also, above the level of the streets, even without preparation, men will not be seen from the street when a little retired from the window, from which they can fire in a stooping posture, and then drop behind the window-sill.

v. Obtain as much as possible on every side a defence by a *flanking* fire. This is of the greatest importance—one loophole that *flanks* a line may be worth twenty direct from it.

To an assailant it is the most discouraging opposition that can be afforded; every spot being seen from the flanks, there is less uncertainty and liability to false alarms as to the operation of the attack, the fire will be deliberate, thus economizing the ammunition, and finally much fewer men might effectually defend premises so prepared.

Flanks are more particularly necessary to command the entrances than for other parts, or, as a substitute, a machicoulis is the next best precaution.

It is to be observed that where it may not be practicable to establish more than even a single loophole, the fire from it may be constant, and very heavy, by applying to it several men and muskets.

vi. A perfectly free, light, ample, and secure communication should be established all through the premises that are under one arrangement within the enclosure, so that every post can be visited, reinforced, or supplied with anything needful.

This requires little or no consideration in the case of an ordinary single building, but will need preparation in extensive premises consisting of a complicated mass of buildings, with perhaps open courts, out-houses, &c.

vii. If the establishment to be protected is *within* a city, and surrounded by streets and houses, it will be a primary consideration how it is to be relieved or withdrawn, or how it may be practicable to secure communication with it when necessary; for posts may be exceedingly strong for self-defence, and yet be in danger of being isolated and cut off by a formidable insurrection.

This was the source of the principal amount of disaster at Buenos Ayres, in the year 1807; the British troops obtained possession of the different strong buildings thought necessary, in which they could defend themselves well; but the natives having occupied the adjoining buildings and streets, these troops could neither retire nor obtain support, and were consequently obliged to surrender.

viii. The nature of the roofs must be considered, for it may be possible by them to obtain many advantages:

1. As situations for defence, giving great command, and flanking points.
2. Also they may afford means of offence by a ready and easy way for penetrating into adjoining buildings.
3. For lines of communication.

To render them capable, however, of these services, the parapet walls must be high enough to cover the men behind them.

The roofs may also require attention from the circumstance of their presenting a direction from whence an attack may be made on the garrison.

General Observations and Arrangements.

The best precautions the premises will afford must be taken against their catching fire: a free communication and constant observation, with tubs or even jugs of water about the house, will most probably afford means, by very early application, for extinguishing any symptoms that might appear.

Besides the posts allotted to the respective parts for defence, there will, of course, be a reserve selected from the best of the garrison to reinforce or support any point; and should the enclosure be penetrated, the entrance would be only by a narrow opening, or defile, where this reserve would be able to attack the assailants to great advantage.

Attempts will hardly be made to enter the premises by any other course than the

doors or any very low and accessible windows; it is therefore to them that the principle resources for obstruction and defence will naturally be applied. On this account even a short preparation may afford a considerable power of resistance.

Bars and struts may be applied that will render it very difficult to force them by ordinary means.

If not rifle-ball proof,* which they never are, except where expressly made to be so for defence, the defenders may fire direct through them at persons attempting to force an entrance; and this would have the greater effect, as it would, no doubt, be unexpected.

Whenever a party have to shut themselves up for protection, it is most desirable that they should have plenty of provisions for the most extreme emergency that can arrive, so as not to require to open a communication to the exterior solely to obtain food, or to be without it for a single meal. A few bags of biscuit and some salt meat afford the most perfect resource, but fresh bread and meat will suffice for most ordinary occasions.

Whatever provision, however, may be made for food, it is indispensable to provide plenty of water to drink.

A very important precaution is, *not to waste ammunition;* let the use of it be confined to what is really and absolutely required, and let it be applied only where it can be effective.

Many a detachment or post has been driven to the greatest extremities for want of this precaution, and even when the inconvenience has arisen from a clearly thoughtless *waste* during the early parts of the contest.

With regard to the general comprehensive arrangements for the protection of public establishments in a city, and for overcoming insurrection, it should be borne in mind that regular troops are most favourably circumstanced when enabled to act in masses and in the open field, and consequently have relatively the least advantage when shut up in separate detachments and posts,—and more particularly when those posts are within towns. Under the circumstances we are contemplating, they must be very much so distributed, but it should be in as little a degree as possible, consistent with the security that it is absolutely necessary to give to the different situations.

Thus as many irregulars as possible, public servants, and well-disposed inhabitants, &c., should be armed and organized: these may be very effective behind the walls, if supported by a small detachment of the troops.

The regular forces should be reduced in proportion to the less value of the premises, or the comparative improbability of their being attacked; and, above all, no dispersion of the troops and means should be made among buildings within a town either for the sake of obtaining cover, or under the idea of having generally a force in each locality.

The best course is to occupy only the points that are absolutely necessary, either on account of their own value, or for some military advantage; to engage in them the smallest number of troops that is consistent with prudence, and to have all the rest of the regular forces collected round the skirts of the town, or even at any distance within about a mile, and well prepared for penetrating in any direction, and in particular to maintain a certain communication with each of the occupied posts.

Great advantage may frequently be obtained by studying the situations of the public

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* To afford rifle-proof cover under close fire will require a thickness of 6 inches of solid oak, 15 inches of deal, between 3-16ths and $\frac{1}{4}$ inch of *homogeneous* iron plate, or from 12 to 15 inches of earth in sand-bags in proportion as it is loose or very compact and solid.—*Editor.*

and other premises requiring protection, with a view, as much as possible, of combining several into one system, by establishing free and secure mutual communication with each other, and from one common centre of reserve.

When so connected, it may be possible, in addition to other advantages, to cover openings for timely sorties by the defenders on the flanks of the assailants.

However improbable may be the chance of the attack of public premises, it will be advisable not to lose sight of any of the above measures of precaution and arrangement that can be adopted without inconvenience to the accommodation, disfiguring the architecture, or bearing the appearance of apprehension.

If attended to, everything required might be easily applied in the first construction, and very much even subsequently.—J. F. B.

SURVEYING.*

TRIGONOMETRICAL SURVEY.

By this term is understood a survey founded on a regular system of triangulation, whether the object of it may be the accurate topographical delineation of a county, province, kingdom, or of any extensive portion of the earth's surface, or the more philosophic purpose of determining the lengths of arcs of great circles of the earth in various latitudes, from which the figure of the earth itself may be deduced.

Grand trigonometrical surveys have, since the vast importance of accurate maps in forwarding practical sciences has become acknowledged, been undertaken in India, America, and almost all the principal nations of Europe; but though the principle of all such surveys, whatever may be their comparative magnitude, must be the same, the details of execution will necessarily vary with the circumstances of the country to be surveyed. In this article some of the apparatus and arrangements hitherto adopted, especially in the Survey of the United Kingdom, will be described; but it must be left to the Engineer to select the particular system he may think best suited to the survey he is called upon to effect, and to adopt, modify, or alter the apparatus to suit the special circumstances. In all such works he will readily perceive that the extent of accuracy which the operation requires must materially influence him in the selection both of instruments and of system.

Selection of ground for a base, and first considerations.—The ground selected should be as nearly level as possible. The soil should be firm. The extremities of the base should command a view of as many accessible elevated points as are necessary for the extension of the survey.

The ends of the base ought to be marked in a very accurate and permanent manner, which is best effected by letting into a block of stone set firmly either in the earth, or in masonry, a metal wire, on the upper surface of which the precise point may be marked by a puncture or dot, of fineness commensurate with the accuracy of the measurement. Old guns may be fixed vertically, to mark by the axes of their bores the ends of a base. Wooden pipes are objectionable, because they decay in the ground. Precautions to secure the marks from disturbance should not be neglected, nor the means of readily detecting such disturbance, should it have taken place.

A transit instrument, or a superior theodolite, will be necessary for arranging all the points of the base in one right line.

Spirit-levels are required to regulate the heights of the ends of the measuring apparatus.

* By Lieut.-Col. Hamley, Royal Engineers.

Tents for the protection of stores and shelter of the party should be provided.

A portable canopy for the measuring apparatus is desirable. (See Sketch, Plate II., from Plate IX. in Colonel Yolland's Account of Lough Foyle Base.)

Carpenters' and intrenching tools, as also earth-rammers and mallets, will probably be required.

The party employed should be proportioned to the magnitude and importance of the operation. As a guide, the following return of the strength of the party employed on the Lough Foyle Base is supplied. This base is nearly eight miles long. The number of Officers of Engineers was at first four, afterwards five.

Return of the Effective Strength of the Party employed in the Measurement of the Base Line on the Shore of Lough Foyle, exclusive of Officers.

Date.	Royal Sappers and Miners.					Royal Artillery.						Total No. of Military.	Civil Labourers.	General Total.
	Serjeants.	Corporals.	Buglers.	Privates.	Total.	Serjeants.	Corporals.	Bombardiers.	Buglers.	Gunners and Drivers.	Total.			
1827.														
Sept.	1	1	1	12	15			4		8	12	27	4	31
Oct. 16	2	2	2	19	25	1	1	4		21	27	52	3	55
1828.														
June 27	1	1		3	5			2		7	9	14		14
July 4	2	1		5	8			8		20	28	36		36
31	1	1		6	8			6		12	18	26		26
Aug. 31	1	1		6	8			2		5	7	15	1	16
Sept. 30	2	1		6	9			8		20	28	37	3	40
Oct. 31	2	2		6	10			8		21	29	39		39
Nov. 30	2	2		4	8			5		13	18	26		26

Measurement of a base.—This has been effected in various ways, all giving results not far from the truth, but some manifestly liable to error in a greater degree than others. Rods of seasoned deal will vary perceptibly in size according to the state of the air. Glass tubes, besides being liable to alter their length according to the temperature, are extremely troublesome to adjust so that confidence may be felt in the result. Steel chains cannot be equally supported at all points, and when stretched by a weight are liable to alter their length, especially with the varying tension consequent on difference of temperature. And the compensating apparatus is superior only when the bars composing it are at exactly the same temperature, and have been, by suitable coatings or surfaces, rendered proportionally (with respect to each other) susceptible in all temperatures.

The errors consequent on change of length by temperature in any ordinary measuring apparatus, such as glass rods or chains, are of course removed by properly applied corrections; but in the compensating bars the correction is a mechanical one, and to be satisfied of its perfect action, the coincident temperature of the bars should be as carefully observed as in the other cases, to deduce the amount of correction.

The compensating bars may be considered the most accurate, the glass rods and steel chains about equal as regards accuracy, and the deal rods the least accurate. Yet as, in certain situations, and for certain objects, dispatch and economy may demand as much regard as extreme accuracy, an officer will judge from the following comparison how nearly he may hope to approach the truth with deal rods, glass rods, or the steel chain.

The length of the base on Hounslow Heath, as found

	Feet.
By deal rods	27,405·7607
By glass rods	27,403·38
By the steel chain . . .	27,402·38

the extreme difference being 3 feet 4 inches in a distance of rather more than five miles.

In using rods of deal or glass, care must be taken—1st, that they are trussed laterally and vertically; 2ndly, that they are laid always in the same right line, whether it be in a horizontal plane or the hypothenuse of a right-angled triangle; 3rdly, that whether they are brought together by contact of the ends or by coincidence effected by placing them side by side, so that two fine transverse lines on either rod may be in one straight line, the junction is equal in all cases; and 4thly, that the temperature of the rods at every stage of the measurement is registered; so that the total number of lengths may be reduced to one standard temperature.

In using a steel chain, the same care as to contact is necessary, as is also precaution against flexure. The chain must be stretched always by the same power, and that power must be so proportioned to its strength that there shall be no danger of the length being increased. The temperature must be noted in this case also.

With the compensating bars, as used in the British Survey, neither contact nor coincidence *could* be adopted, connection being effected by intervening microscopes; and the precautions to be most insisted on are, that each pair of bars should be quite horizontal, and that the measuring points should be always in one vertical plane.

The deal rods used in England were 20 feet long, 2 inches deep, and 1¼ inch broad; the ends were tipped with bell-metal. The method of measuring by coincidences of the transverse lines was thought more accurate than that by butting the ends one against the other; but it was found so troublesome in practice, that, after a few lengths had been measured, it was abandoned, and the other mode adopted. The ground on which they were used not being level, it was divided into several parts, and each part represented the base of a right-angled triangle, the perpendicular of which was a vertical line. The lines actually measured were the hypothenuses of these triangles (each 30 rods long), and their bases, whose sum made up the base of the survey, were found by computation, the height of the perpendiculars having been ascertained by the spirit-level. The rods were supported on trestles from 2 to 3 feet above the ground: a plumb-line marked the extremity of each day's work. The plummet vibrated in a brass cup of water placed in a hole in the ground; it was fenced round for the night, and a watchman guarded the ground till operations were resumed.

The steel chain was 100 feet long, each link a parallelopiped, half an inch square, and 2½ feet long; there were, therefore, 40 links. In measuring, it was placed on coffers, which were supported by posts driven into the ground. A weight of 56 lbs. at one end, and a screw at the other, stretched and adjusted the chain. A moveable scale, supported on a post, but entirely independent of the rest of the apparatus, was made to mark accurately the end of each 100 feet measured, and the commencement of the 100 feet about to be measured, so that one chain was sufficient for the work. Nevertheless, as the end of a 100-feet chain might sometimes fall in a ditch or other irregular ground, a second chain of 50 feet long, and laid off from the same standard as the 100-feet chain, was kept ready for such a contingency.

The expansion of a foot of the glass tube and of a foot of the steel for every degree of the thermometer was ascertained by a microscopic pyrometer.

The compensating bars used in Ireland measured each a distance of exactly 10 feet between the compensating points. The following will explain their construction* :—

"Let $a\ a'$, $b\ b'$, be two bars of brass and iron joined together at their centres by a steel bar, $p\ q$, but free to expand from and contract towards their centres, independently of each other; $a\ n$, $a'\ n'$, are flat steel tongues at the extremities of these bars, moving freely on conical brass pivots, allowing them to be inclined at small angles with the lines perpendicular to $a\ a'$, $b\ b'$. (Fig. 1, Plate III. Lough Foyle Base.)

"At the temperature of 62° Fahrenheit, the bars are assumed to be precisely of the same length, and the tongues consequently at right angles to $a\ a'$, $b\ b'$.

"Imagine these bars to receive an increase of temperature and length, and, from the inequality in their expansions, the brass to become $c\ c'$, and the iron $d\ d'$, the position of the tongues now being $c\ d\ n$, $c'\ d'\ n'$, it will then be apparent that if the points $n'\ n'$ be so determined that

$a\ c$	:	$b\ d$	: :	$a\ n$	:	$b\ n$,
Expansion of the brass	:	expansion of the iron	: :	distance of the compensated point from the brass	:	distance of the compensated point from the iron,

the positions of the points $n\ n'$ can only vary within very narrow limits for any differences of temperature arising from atmospheric changes."

In arranging these bars for measurement, triple microscopes, also constructed on a compensating principle, measured an equal interval between the points of every two adjacent pairs of bars, and thus all danger of disturbance by contacts was avoided.

The following are the reductions and reduced lengths of General Roy's base, measured with glass rods :—

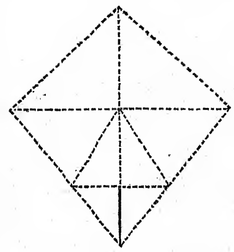
	Feet.
Hypothenusal length of the base as measured by 1369·925521 glass rods of 20 feet each + 4·31 feet, being the distance between the last rod and the centre of the north-west pipe	27,402·8204
Reduction of the hypothenuses to be subtracted	0·0714
Apparent length of the base reduced to level of south-east extremity .	27,402·7490
Add the difference between the expansion of the glass above, and contraction of it below, 62°	0·3489
Add also the equation for 6° difference of temperature of the standard brass scale and the glass rods, between 62° and 68°, the temperature at which the rods were laid off	0·9864
Length of the base, in temperature 62°, reduced to the level of the lower extremity	27,404·0843
Reduction from the height of the lower end of the base above the mean level of the sea, supposed to be 54 feet	0·0706
True length of the base reduced to the mean level of the sea . .	27,404·0137†

A base may be tested by dividing it into two parts and using one part as a base from which the other part may be found trigonometrically. After being tested in this way, a base may be prolonged by the same means with the greatest accuracy.

* See also page 599.

† The length of the base, as found by the glass rods, differs from that given in page 578, because it is there reduced to the standard from which the steel chain was laid off.

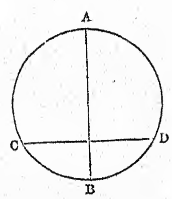
This method of throwing out perpendiculars at the end of a measured line, and then extending it thus by triangulation in successively augmenting lengths, has been adopted by preference in some cases to an actual measurement, and wherever it is only possible to secure a very small portion of good ground, it deserves such preference. It was adopted in the Irish survey in order to extend the measured base to a favourable point for observation, over a tract of sand-hills. By such an arrangement very great care may be bestowed on the measurement of a small base, without incurring the great expense of a more protracted measurement, and for minor surveys, therefore, it is a most valuable method.



Grand Triangulation—Elevations and Depressions—Observations of the Pole-Star.

It has always been a maxim in England, among those who have conducted our grand trigonometrical operations, that reductions in the office should be avoided by every means that science and art afford for perfecting the field operations. The time and labour expended by us in the field are therefore considerable; but it is hoped that the precision of our measurements and observations is considerable also. The circle of repetition, so generally used by the French, has not been adopted by our engineers; and our instruments are less portable and less expeditious, but capable of being accurately adjusted to the plane of the horizon, and the vertical plane, and of being placed exactly over the station. The principle of these instruments is of the same nature as that of the theodolite in general use; but their form and construction are peculiar, and designed to secure the utmost precision. The largest, or Ramsden's great theodolites, made for the Royal Society and for the Ordnance, have a horizontal circle of three feet diameter, connected by strong radii with a hollow conical axis two feet high, which is a socket for an interior axis rising from the base of the instrument. The exterior axis carries two arms for the support of a powerful telescope. The reading is effected by means of microscopes which are attached to the base of the instrument. Their number was originally two, placed at 180° interval; but it has been increased to four in the Ordnance Survey instrument, the additional microscopes being so placed that, together with one of the original microscopes, they divide the circle into three equal parts or into divisions of 120°, and it has been customary to record the mean of the two opposite microscopes marked A B, but to use for the calculations the mean of the three A C D only; * the object being the more effectual correction of errors from eccentricity. In the

* On the azimuth circle of the large theodolite used on the triangulation of the Ordnance Survey, the original verniers were only at the two opposite points A and B, the mean of the readings at which was, of course, always taken. Subsequently, the verniers at C and D were added, each of them equidistant 120° from A, and also from each other. It has since been sometimes the custom, first to take the mean of A and B, and afterwards the mean of A C and D, and to consider the mean between these two valuations as the true reading of the angle: this method has, however, been objected to as being incorrect in principle, an undue importance being given to the reading of the vernier A, and also in a smaller degree to B. The influence assigned to each vernier is, in fact as follows:—A . 5; B . 3; C and D, 2 each. A theodolite of the same size and construction has since been made with four equidistant verniers.—*Outline of the Method of conducting a Trigonometrical Survey. By Colonel Frome, R.E.*



instrument belonging to the Royal Society four additional microscopes were placed, so that the circle is divided by them into six equal parts or divisions of 60 degrees; and the mean of the six is then taken as including in itself each case of correction.

The microscopes are micrometers, the minutes being shewn by a divided scale, and the seconds by a graduated circular rim attached to the screw-head, which moves the bisecting wire of the microscope. It is of course necessary, before commencing observations, to adjust the zero of the scale and that of the micrometer screw-head to each other, and also to adjust the several microscopes to each other; which is readily done by causing the bisecting wire of any one microscope when over the zero of the scale (the index of the graduated micrometer rim being also at zero) to bisect a dot of the circle, say 0°—60°—120°, or any other, and then carefully adjusting every other microscope to the dot corresponding to its relative position.

The vertical circle is fitted to the transverse axis of the telescope, and its divisions read by a microscope on an index fixed to the arms which support the telescope. The telescope can be inverted in its supports or Y's. The parts of the instrument are capable of the most delicate adjustment, and no skill nor expense has been spared that could contribute to their efficiency.

Each instrument, when not in use, can be enclosed in a wooden case, and travels in a spring waggon constructed to receive it and its stores. It is carried by hand, on a cradle, up hills impracticable for wheeled vehicles, and hoisted by mechanical power to the tops of buildings.

An instrument 18 inches in diameter, and of a construction similar to that of the three-feet instrument, has been used in situations to which the greater instruments cannot be conveyed.

An altitude and azimuth instrument, differing in construction from the great theodolite of Ramsden, was made by Messrs. Troughton and Simms for the Survey of Ireland. The horizontal circle of this instrument is two feet in diameter, and fixed, whilst the reading microscopes are moveable, being attached to arms projecting from the moving axis; whereas in Ramsden's theodolite the microscopes are fixed and the divided circle is moveable. In Ramsden's instruments the brass cone to which the circle is attached, as well as the apparatus for carrying the Y's of the telescope, moves round a long vertical steel axis, so that the telescope cannot be reversed without being lifted out of the Y's: in Troughton's the axis is very short, and the telescope is supported by pillars rising from the axis, so that it can be reversed without removal. This important difference of principle, whilst it facilitates the application of the instrument to the determination of vertical angles, renders the preservation of its level uncertain; and although it has been so modified as to give, in skilful hands, results equal to those of the three-feet theodolite, it is still considered an instrument of very difficult use. It was furnished originally with a repeating-table on Pond's construction. It may be stated that in Colonel Yolland's opinion neither of these instruments is equal to the requirements and resources of modern science—an opinion shared by at least one of his predecessors, who had a long experience of the use of the three-feet theodolite; and it is to be hoped therefore that an opportunity will be afforded during the progress of the survey to Colonel Yolland to bring forward an improved construction, so that the British survey may take the lead in the instrument for measuring angles, as it has done in the apparatus for measuring a base.

Instruments whose circles are divided from 0° to 360° are, *cæteris paribus*, much to be preferred to those whose circles are divided from 0° both ways to 180°.

In all situations where the instrument may be set up, the following are rules to be strictly attended to:

1. That the centre of the instrument be placed vertically over the centre of the station, so that the two centres may be in the same vertical line.

2. That the instrument be insulated from all parts of the observatory.

3. That the footing of the instrument be perfectly secure and constant.

On buildings, or artificial stations, these effects must be secured by means adapted to the particular circumstances of each case; but on open or natural stations the instrument must be supported on wooden posts, firmly tied together, and either resting on a rock, or driven into a substratum not liable to transmit vibrations from any lateral shock. The frame-work and floor of the observatory must be entirely separated from the supports of the instrument,* so that the latter may be perfectly insulated, and secured from the influence of the vibrations of the floor. In rock the transmission of vibrations is so very imperfect, that, though the supports of the floor and those of the instrument are kept distinct, they may all rest upon the rock; but in soft ground it would be frequently necessary to sink a shaft in order to secure a non-vibratory stratum for the support of the instrument, the observatory resting on the natural surface.

The portable observatories are furnished with strong guy-ropes to support them in the exposed situations where they are commonly set up.

A party of ten or twelve men accompanies the instrument; and these must be accommodated in tents or portable huts, and carry a camp equipage sufficient for their wants at remote and exposed stations. Plate I. is a sketch of an encampment.

In any series of observations the telescope should be always directed on the objects by the same person; and each microscope should be read by the same person, because of the difference in men's visions.

At every observatory station, an object near at hand, and likely to be visible in all states of the atmosphere, should be selected as a referring point, and observed in each series of observations. Between two successive sets of observations the position of the horizontal circle should be changed, so that the bearings of the several objects should be read on different parts of the circle, and errors of division be, as much as possible, neutralized. It is not necessary to set the zero of the circle to any one object, nor to adjust it to the index of the vernier or zero of the microscope; as the observation, in every set, of the referring point, enables the bearings of all other objects to be referred to it as a zero point, by the subtraction from the respective bearings of an angular quantity, namely, the bearing of that referring point in that particular series.

It is proper also to invert the telescope in its Y's occasionally, so that the successive series may be taken with the telescope in the one or in the other position, alternately,—as well to compensate for errors of collimation as to guard against an unequal wear of the axis.

A long series, including principal stations and minor objects, is liable to interruption or vitiation by sudden or partial atmospheric changes, or by the instrument falling out of level. On the other hand, the general accuracy of the whole work is advanced by having as large a number of points as possible observed under the same circumstances, which can hardly be the case if they are observed in different series; as the parts of the circle on which the bearings are read, the temperature, and state of the atmosphere, will probably be changed, and there may be a different observer.

An officer must therefore be guided in the arrangement of his series of observations by the time at his disposal for the completion of the station, considered in connection with the season of the year and the prevailing weather.

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* See article 'Observatory,' vol. ii.

The nearer stations will be often visible when the more remote are hidden by vapours, therefore the observations to the former will exceed in number those to the latter. It will be hereafter seen how the number of observations to any two objects affects the value of the contained angle for calculation.

Any principal station ought to be observed not less than three times from any one station of the instrument.

The depressions and elevations are found by setting the telescope horizontal by its level, and at the same time adjusting the index so that it shall read zero ; or, if it be preferred, the exact reading of the index, when the telescope is level, may be registered, and the error, if any, allowed for. Then by directing the telescope on the base or some appointed part of the object, the angle contained between it and the plane of the horizon is measured on the vertical circle, and read by the microscope at the index.

It has been the custom to measure first the horizontal bearing of an object, and afterwards its elevation or depression.

To find the direction of the meridian at any station, the angles contained between any fixed terrestrial object and the greatest apparent eastern and western elongations of the pole or other circumpolar star may be observed. The mean of these observations is the angle contained between the pole and that object. The most convenient object from which to measure the direction of the meridian will be the referring object before mentioned.

As some of the observations have to be effected by night, it is necessary on such occasions to illuminate the wires of the telescope and also the referring object. To admit of the illumination of the wires, the transverse axis of the telescope is made hollow, and has an elliptical illuminator in the centre; its end is covered with glass, so that the light of a lamp placed for that purpose on a stand enters and is thrown on the wires. The referring object can be easily constructed so as to have a lamp fitted to it for nocturnal observations. The times of the greatest elongations of the pole-star * must be calculated from astronomical data, and the observer must ascertain the right moment by means of a chronometer or good watch.

The true meridian may also be determined by observing Polaris or some other convenient star frequently when near its maximum elongation, in successive bearings, the times of observation being accurately noted, and then by calculation deducing the true bearing of the star when on its meridian. With the repeating circle this is the necessary arrangement. These methods are intended to secure a degree of accuracy in the azimuths corresponding to that obtained in the distances between objects; as without such accuracy latitudes and longitudes could not be determined geodetically with sufficient precision. For more ordinary purposes, when the object is merely to determine with a moderate approach to accuracy the variation of the needle, or place the meridian on a map or plan, equal altitudes of the sun may be used.†

All observations should be recorded in ink; and if the observer have any reason to doubt the accuracy of an observed bearing or series of bearings, he should record his opinion at the time.

The date, name of the observer, and state of the atmosphere, should be recorded with every series.

Corrections in the record-book should be made by scoring out with the pen the

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* This, of course, is not applicable in Southern latitudes.—*Editor*.

† Allowance being made for the sun's change of declination during the interval. Equal altitudes of a *star* require no such correction.—*Editor*.

incorrect word or figure, and writing the correct one over it. Erasures with a knife should never be permitted.

The accuracy of the results of triangulation must mainly depend on the care with which the stations for observation are preserved and identified, and on the stability secured for the instrument. When the points for observation have been selected, they should be marked with an accuracy corresponding to that expected in the observations from and to them. In treating of the measurement of a base, the more delicate modes of marking the centre of a station have been pointed out, but it has been usually considered sufficient to mark the centres of ordinary stations by a jumper-hole in the rock or in a large stone buried about two feet under the surface. On the British Survey the object to be observed is either a pole or a staff, the lower portion of which is surrounded by a conical pile of sods or of stones, or the simple pile itself. In either case, the strict verticality of the object must be carefully insured. During the earlier years of the Survey a pole was placed in every pile, to assist the eye in the bisection; but of late years it has been considered sufficient to build carefully the pile concentric with the station, as the pole was thought to take the wind and draw out of the perpendicular, and tend to shake down the pile. On the hills of Scotland it would have cost some labour and expense to convey poles to the hill-tops, and in the lower grounds the peasantry are tempted to destroy the pile for the purpose of appropriating the wood. The piles vary in height according to the distance from which they are to be observed, from 12 to 18 feet, with a diameter of base sufficient to give stability. The poles or staves have varied from 24 to 30 feet. When a building is the point to be observed, some definite and readily recognizable part should be selected, and if there be none such, a pole or other object should be raised upon or fixed to it, as the observation of the apparent centres of large buildings is a very rude process and leads to much inaccuracy. In addition to these ordinary modes of marking stations, which will, of course, be modified by every ingenious Engineer so as to meet the requirements and resources of the country he may be in, it is frequently necessary to use more refined methods of exhibiting to a distant observer the point to be observed, and this more especially in countries where a hazy or misty condition of the atmosphere prevails. A tin cone or sphere has been observed as a very brilliant object, but as it exhibits varying phases it is objectionable; and this objection applies even to stone piles when not provided with central poles, as they are often partially and brightly illumined, and are then liable to be observed incorrectly, the apparent not being the true centre. Metallic plates have been fixed to a pole and arranged in angles corresponding to the varying altitudes of the sun; but this, though an ingenious, is a very troublesome, method of insuring a reflection of light in a definite direction. The Drummond light, or the intense light evolved by lime when brought to a state of high ignition by the action of the oxy-hydrogen blow-pipe, was used once on the Irish Survey; and judging from its brilliancy on that occasion, it cannot be doubted that for any particular and very distant object where a night signal is desirable, the Drummond light may be used with effect and for any distance; but the skill and attention necessary to prepare the oxygen gas and to watch over the lamp and reflection will prevent its use on lofty mountains or in ordinary circumstances. The Heliostat, or Heliotrope, is the instrument which, from the facility of its application, has been most approved by modern Geodesists. There are several forms of this instrument, such as that of Gaus, used on the continent, and that of the late Captain Drummond, used on the British Survey. The object of such instruments is to insure the reflection of the sun's rays in some definite direction by a mirror, the movement of which is adjusted to the motion of the sun. In Gaus's Heliotrope the mirror is small, and when the observer looks through a telescope

which forms part of the instrument, at the station to which the reflection is to be made, he sees (if he has rightly adjusted the instrument) a reflected image of the sun before him, and knows that its rays are then reflected from the mirror in the right direction. In the original Heliostat of Captain Drummond also there was a tolerably good telescope for determining the line of direction; and the mirror, which varied in size from 8 to 12 inches square, was adjusted by machinery connected with a small telescope, with which the observer followed the motions of the sun. This, though ingenious in construction, was troublesome in use, and was replaced by a very simple arrangement, also devised by Captain Drummond. The line of direction being first determined approximately and then marked by means of a small theodolite or other instrument on the ground, a small brass ring is placed about 50 or 60 feet in front of the mirror, being adjusted as to height to the degree of depression or elevation which may be required. The operation is now perfectly simple, as the person in charge of the Heliostat merely moves the mirror horizontally and vertically until he observes the ring before him illumined by the rays reflected from its surface, as it is then manifest that the reflection is made in the required direction. As this very simple arrangement has been found effectual with distances exceeding 100 miles, it appears to require no further recommendation for the greater distances, and as small circular mirrors of 4 inches diameter are amply sufficient for distances of 30 or 40 miles, they can be readily applied in low situations, where it is often extremely difficult to discern an opaque object. In the Survey of Ireland they were extensively applied in this manner, being packed in a leathern case slung over the back of a soldier who went from one station to another, and thus enabled the observer at a station to include in his observations many of those difficult minor objects in the low country around him which would perhaps, without this aid, have baffled his efforts to see them. A common mechanic may construct one of these simple heliostats, and they may therefore be applied under almost any circumstances, as was done by Mr. M'Clear at the Cape, who used a simple chamber looking-glass fixed in by swivels to a double frame.

When the instrument leaves a station, the posts on which its feet rested are left in the ground, as well as the centre stone. The description of each station, with its distances from permanent objects, should be recorded at the time of its selection, to prevent the possibility of its being lost.

It is most desirable that, in the grand triangulation, all three angles of each triangle should be observed.

As a guide in the selection of stations, it should be remembered that the conditions which afford the greatest probability of the smallest errors are these:

1st. That the angle opposite to the measured side be less than a right angle; and 2ndly, That the angles adjacent to that side be nearly equal. These conditions will be best fulfilled, on the average of a series, by making the triangle as nearly as possible equilateral.

The Secondary Triangulation will not require a lengthened notice, as it is simply the breaking up of the grand triangulation into smaller triangles, and these again into still smaller triangles having sides not exceeding two miles in length, and is founded on the same principles. The angles are taken with instruments of 12, 10, and 7 inches diameter. The stations are marked either with small piles of earth or stone, or by poles. The minor stations being necessarily in fields, villages, gardens, &c., where they are liable to be disturbed or defaced, it is desirable that a district should be speedily completed, and the detail survey commenced as soon as the distances can be computed. Therefore many instruments should be simultaneously employed at this secondary triangulation.

It is not always necessary to erect an observatory; but to shelter the instruments and observer when an observatory is dispensed with, one of the assistants carries a large chaise umbrella, or any other description of simple screen.*

Sector Observations.—For purposes to be hereafter mentioned, it is requisite to measure the zenith distances of known stars at certain of the trigonometrical stations. This is effected with an instrument called the 'Zenith Sector:' it is of various constructions, which it is not necessary here to detail, but the general principle is as follows. Two strong bars or pillars are joined at one point only, which is the centre of the instrument. One of them is immoveable and vertical, the other has a motion in a vertical plane round the centre, limited according to the lengths of the arcs to be measured. The moveable bar carries a telescope, to be directed on the object whose zenith distance is required. The angle contained between the vertical line through the centre of the instrument and the axis of the telescope directed on the star is the zenith distance, which must be measured on the arc of a metal circle attached to either the fixed or the moveable pillar.

The construction of the sector now in use on the Ordnance Survey is quite new. The vertical bar is furnished with two concentric graduated arcs, one above and one below the centre, and the axis of motion of the telescope is at the middle of its length. At the eye end, cast in the same piece with the tube of the telescope, one on either side of it, and looking towards the lower arc, are two microscopes, and the same at the field end. The mean of four readings is therefore obtainable for the bearing of the axis of the telescope as shewn on the arcs. The whole instrument can be suddenly turned round 180° in azimuth by means of a stop; and it must be so turned between every pair of observations of the same star. It stands in a sort of tray, in which are strong screws for adjusting it in the plane of the meridian; and the vertical bar has three levels behind it: a clamp and tangent screw arrest and regulate the motion of the telescope, and a micrometer wire in the focus of the telescope is moveable by a screw over the field.

Suppose the instrument set up and adjusted to the plane of the meridian, and that it is intended to measure the zenith distance of a star; two persons must take part in the operation. The direction of the star when on the meridian being approximately known, the telescope is set accordingly, and clamped before the time of culmination, and the four microscopes read off and registered, as also the inclination, if any, of the levels. Then when the star appears on the field of the glass, it is bisected with the micrometer wire before it quite reaches the meridian, and the time noted: thus the bearing of the line from the eye of the observer through the wire to the star is already registered. The instrument is then reversed by the stop, and the levels again read by one person, while the other again bisects the star, but this time with the tangent screw, the micrometer wire remaining as at the first observation; and the time is again noted. The four microscopes are then read again; and the difference of the two readings is, of course, double the zenith distance of the star.

Computation of Distances, Altitudes, Latitudes, and Longitudes.—The mean value of each of the angles of a triangle having been found from the observation book, their sum ought, strictly speaking, to equal 180° + the spherical excess. To compute the spherical excess. †Let A, B, C denote the angles of a spherical triangle, r the radius of the sphere expressed in feet, $\pi = 3{\cdot}14159$ the ratio of the circumference to the

* To shelter the instruments and also observers from the weather, portable observatories are used, as described in the article 'Observatory, Portable.'—*Editor.*

† Rule by Mr. Airy, Astronomer Royal.

diameter, and S the number of square feet in the surface or area of the triangle: then, by trigonometry,

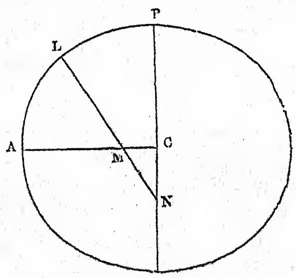
$$S = \frac{A + B + C - 180^\circ}{180^\circ} r^2 \pi.$$

Let E denote the spherical excess $= A + B + C - 180^\circ$, then $E = \frac{S \times 180^\circ}{r^2 \pi}$ in degrees, or $E = \frac{S \times 648000''}{r^2 \pi}$ expressed in seconds.

In any triangle which can be measured on the surface of the earth, S is very small in comparison of r^2, and therefore E is a very small quantity. (In practice it seldom exceeds four or five seconds, though in some of the large triangles observed in the west of Scotland, whose sides exceed 100 miles, it amounted to thirty or forty seconds.) Hence an approximate value of S will enable us to compute E with sufficient precision. For this purpose, therefore, the triangle may be regarded as a plane one; and on denoting by a, b, c, the number of feet in the sides respectively opposite to A, B, C, we shall have for the area, $S = \frac{1}{2} a b \sin. C$. Substituting this in the formula for the spherical excess, we get, in seconds,

$$E = \frac{a b \sin. C \times 648000}{2 r^2 \pi} \quad . \quad . \quad . \quad . \quad . \quad (1).$$

In order to compute the spherical excess of any triangle, it is necessary to know the value of r, the radius of curvature of the spherical surface. Now, the curvature of the arc joining any two stations on a spheroid varies with the latitudes of the stations, and also with the direction of the arc in question in respect of the meridian; but for the present purpose it will, in general, be sufficient to assume the value of r, which corresponds to the curvature of the meridian at the mean latitude of the stations, and even to suppose it constant for a whole series of triangles contained between two parallels of latitude not distant more than a few degrees. If, however, the triangles are very large, it may be necessary to compute more accurately; and in such cases the nearest approximation to the true spherical excess will be found by computing, for the mean latitude of the three stations, the curvature of the meridian and of the circle perpendicular to the meridian, and taking the mean of the two for the value of r; or, which is nearly the same thing, by computing the radius of the vertical circle which cuts the meridian at an angle of 45° at that mean latitude.



To find the radius of the meridian.

Let A L P be the arc of the meridian passing through the station L, A C the semi-diameter of the equator, C P the semi-axis, L M the normal at L, meeting P C produced in N. Assume $a =$ C P, $b =$ A C, and $e =$ the ellipticity, or such that $b = a\,(1 + e)$, and let l be the latitude of L, and R the radius of curvature of the meridian at L; then

$$R = a\,(1 - e + 3\,e \sin.^2 l) \quad . \quad . \quad . \quad . \quad . \quad (2).$$

Next, let R′ be the radius of curvature of the arc perpendicular to the meridian at L; then R′ = L N, the normal extended to its intersection with the polar axis. Now let $n =$ L M, the normal at L; then, by conic sections, $R' : n :: b^2 : a^2$; whence $R' = (1 + e)^2 n$. But $n = a\,(1 - e \cos.^2 l)$; therefore, rejecting terms containing the square of e, as insignificant, we find

$$R' = a\,(1 + e + e \sin.^2 l) \quad . \quad . \quad . \quad . \quad . \quad (3).$$

To find the curvature of the oblique circle, let r be the radius of curvature at the point L of a section of the spheroid containing L N, and making with the meridian angle $= \theta$; we have the following expression found by Euler:

$$r = \frac{R R'}{R \sin.^2 \theta + R' \cos.^2 \theta}.$$

This last expression may be put under a form more convenient for calculation. Dividing both terms by R′, substituting $1 - \sin.^2 \theta$ for $\cos.^2 \theta$, and converting the result into a series, all the terms of which after the second may be neglected, we get

$$r = R\left(1 + \frac{R' - R}{R'} \sin.^2 \theta\right) \quad . \quad . \quad . \quad . \quad . \quad (4).$$

Since in any circle the length of a degree is proportional to the radius (it is found by dividing the radius by the constant number 57·29578), if we make M = the length in feet of a degree of the meridian at L, P = the length of a degree of the perpendicular arc, and D = the degree of an arc which makes with the meridian an angle $= \theta$, we shall have also

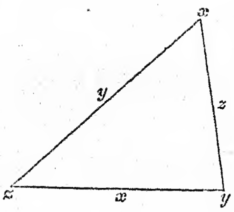
$$D = M\left(1 + \frac{P - M}{P} \sin.^2 \theta\right) \quad . \quad . \quad . \quad . \quad . \quad (5),$$

which is the expression usually given, and by means of which the length of the oblique degree is found in terms of the degrees of the meridian and perpendicular.

Having computed the spherical excess E from approximate values of the lengths of the sides (obtained by supposing the triangle a plane one), the sum of the three observed angles should be $= 180° + E$. But as every observation is attended with some degree of uncertainty, the probability is infinitely small that the sum will be precisely equal to this quantity in any case. The difference (which in general will amount to some seconds) is the error of the observed angles; and the next question to be considered is, how should the error be apportioned among the three angles, so that the probability of the result being true may be greater than if any other mode were adopted? If no reason exists for supposing that one angle has been determined more accurately than another, the error should, of course, be equally divided among the three angles; but in practice this is seldom the case, for it will usually happen that one or other of the angles has been determined by a greater number of observations, or by observations made under more favourable circumstances than the others, and consequently the three determinations are not affected with the same probable errors. In the earlier period of the Ordnance Survey, the apportionment of the error appears to have been made in a manner entirely arbitrary, or at least according to the observer's judgment of the relative goodness of the observations; but this objecticnable practice is now abandoned, and a uniform method, founded on the theory of chances, adopted. Suppose several observations to have been made of the same angle, and that the seconds of reading are l, l', l'', &c., and let m be the average or arithmetical mean of the whole; then $m - l$, $m - l'$, $m - l''$, &c., are the errors of the individual observations, and the *weight* of the determination, or of the average m, is equal to the square of the number of observations divided by twice the sum of the squares of the errors. In this manner the *weight* is found for each angle, and the error of the triangle, that is, the difference between the sum of the three angles (each being the average of the observed values) and $180° + E$, is divided into three parts respectively proportioned to the reciprocal of the weights, which parts form the corrections to be added to or subtracted from the angles to which they respectively correspond. We have then three corrected spherical angles, the sum of which is exactly $180° + E$.*

* The text from the asterisk in page 586 to this is extracted from the article 'Trigonometrical Survey,' in the Encyclopædia Metropolitana, by the Astronomer Royal.

Having got thus far, let us pause to consider an example of what has been laid down, taken from the records of the Ordnance Survey.



In the triangle x, y, z,—x is the well-known hill, Ben Lomond, in Stirlingshire; y, Cairns Muir on Deugh, in Kirkcudbright; and z, Knocklayd, in the county Antrim, Ireland. The side z has been found, by previous computation, 352,037·62 feet; and the angles as observed are

					Mean.		
x	1st time	56°	43′	29″·97	56°	43′	28″·58
	2nd time	56	43	27 ·04			
	3rd time	56	43	28 ·72			
y	Once only	79	42	28 ·69	79	42	28 ·69
z	1st time	43	34	38 ·36	43	34	36 ·89
	2nd time	43	34	35 ·43			
	Sum of all the angles				180	0	34 ·16

The spherical excess must now be computed by the rule already given, as follows:

Having the three angles and one side (it being remembered that for this purpose we calculate only approximately and consider the triangle a plane one) we obtain, by ordinary trigonometrical formulæ,

$$x = 426{,}960{\cdot}0 \text{ feet}, \quad y = 502{,}470{\cdot}0 \text{ feet}.$$

The mean latitude of the triangle is 55° 40′, which will be represented by l in the before-given formulæ (2, 3, and 4), and the quantities a and e are assumed from astronomical data.

$$a = \text{half the polar axis} = 20{,}852{,}394 \text{ feet},$$

$$e = \frac{b-a}{a} = \frac{1}{301{\cdot}026} = {\cdot}003322.$$

Hence by formulæ 2, 3, and 4,

$$R = 20{,}924{,}824, \quad R' = 20{,}968{,}900, \quad \text{and } r = 20{,}946{,}814.$$

Having thus the value of r, we may apply formula 1, which, using logarithms, becomes

$$\text{Log. } E = \text{log. } x + \text{log. } y + \text{log. sin. } z + 0{\cdot}37116$$
$$= 1{\cdot}54108. \text{ So that}$$
$$E = 34''{\cdot}760.$$

Deducting this quantity from the sum of the three angles as found above, viz., 180° 0′ 34″·16, we have the remainder 179° 59′ 59″·40, which falls short of 180° by 0″·60, which is therefore the error of the triangle.

To apportion this error by the rule already given,—the angle x has been three times observed, and its mean value is 56° 43′ 28″·58; deducting each observation from this mean, we get the several errors + 1·39, − 1·54, + 0·14, and their squares 1·9321, 2·3716, and 0·196: the sum of the squares = 4·3233. Then the square of the number of observations divided by twice the square of the sum of the errors = 9 ÷ 8·6466 = 1·041, the *weight*, the reciprocal of which is ·961.

The angle y is but once observed, and the weight is assumed as ·1, the reciprocal of which is 10.

Proceeding with the angle z as with the angle x, we get its weight = ·4660, and the reciprocal thereof 2·146.

We must now divide the error (0″·60) of the triangle in the proportion of the reciprocals of the weights; and thus the error of x becomes + 0″·04, of y, + 0″·46, and of z, + 0″·10; and the corrected angles become

$$\begin{aligned} x &= 56° \quad 43' \quad 28''\cdot 62 \\ y &= 79 \quad 42 \quad 29 \cdot 15 \\ z &= 43 \quad 34 \quad 36 \cdot 99 \end{aligned}$$

and their sum 180 0 34 ·76, that is to say $180° + E$.

Having now the three corrected spherical angles and one spherical side, we may compute the remaining sides by three different methods, viz.

1. By the formulæ for spherical trigonometry.

2. By finding the chord of the given side or arc, and deducing from the spherical angles the angles formed by the chords; then computing the two unknown chords by plane trigonometry, and converting them into parts of the circle.

3. By Legendre's method, which is as follows: From each of the angles (corrected as above) of the triangle deduct ⅓rd of the spherical excess; then the sines of the angles so diminished will be proportional to the lengths of the opposite sides (arcs, not chords).

The second method was for a long time used in the calculations of the Ordnance Survey; but it has of late been superseded by Legendre's simpler method. Let us proceed with our example accordingly.

One-third of the spherical excess we soon find to be $11''\cdot 586$, which, deducted from each of the corrected angles, leaves

$$\begin{aligned} x - \tfrac{1}{3}E &= 56° \quad 43' \quad 17''\cdot 04 \\ y - \tfrac{1}{3}E &= 79 \quad 42 \quad 17 \cdot 56 \\ z - \tfrac{1}{3}E &= 43 \quad 34 \quad 25 \cdot 40 \end{aligned}$$

The side z already known $= 350,057\cdot 62$, and with these data, by the proportion of the sides to the sines of their opposite angles, we get

$$\begin{aligned} x &= 426,974\cdot 06 \text{ feet}, \\ y &= 502,504\cdot 42 \text{ feet}. \end{aligned}$$

and the triangle is solved.

When the heights of stations are required with *extreme accuracy*, there is no less laborious method than that of ascertaining them with reference to a datum point by means of the spirit-level, because the amount of refraction at any given time and place is so uncertain, that results obtained through angles of elevation or depression will be only approximations to the truth. Many reasons may, however, make it desirable to obtain these approximations, and the following is the method.

At present it is the practice to take depressions and elevations to the base of the pile, otherwise a correction would have been necessary for the height to which the telescope was directed above the station. But as the centre of the instrument must always be, from its construction, four or five feet above the station, a reduction to the centre is unavoidable. The reciprocal angles from any two stations A and B having been thus reduced by the common rule,* and the distance A B being known from the triangulation in feet and seconds, we estimate the refraction by the following formulæ:

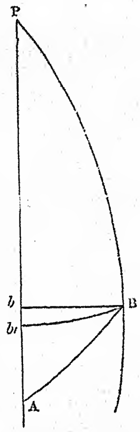
Let d = the observed depression at a,
d' = ,, ,, ,, b,
C = arc A B in seconds,
r = the mean refraction,
ϕ = the difference of altitude between A and B in seconds,
ϕ' = same difference in feet;

* Given in all books on the application of trigonometry to the finding of heights and distances.

then $r = \frac{1}{2}\{C - (d + d')\}$
$\phi = \frac{1}{2} C - (d + r)$
$\phi' = AB \text{ (in feet)} \times \phi \sin. 1''$.

If one of the stations is elevated, then d or d', as it may be, must be taken negatively.

Before the latitudes and longitudes of the stations can be computed from the geodetical observations, it is necessary that the latitude of at least one station, and the inclination to the meridian of one side, should be determined by astronomical means. These obtained, the following rule given by the Astronomer Royal, and now extracted from Colonel Yolland's (R.E.) account of the measurement of the Lough Foyle base, suffices to find the latitudes, longitudes, and azimuths for a series of stations.



Let P be the pole of a fictitious sphere, A P and B P the co-latitudes of the two stations, B b an arc of a great circle perpendicular to the meridian A P, B b_1 an arc of parallel, A B the distance in feet between the two stations, and P A B the azimuthal bearing at A of the station B; then the several steps of the formulæ are:

1st. Convert A B into seconds of arc, using any *approximate radius*;* then solve A B b as a spherical triangle right-angled at b, by spherical trigonometry, having the side A B and the angle at A given.

2nd. Apply the arc A b so found, with the proper sign, to the co-latitude of the station A, for the resulting co-latitude of the point b.

3rd. Solve the triangle P b B right-angled at b, by spherical trigonometry, having P b and b B given, from which will result the co-latitude P B of the station B or b_1, and the difference of longitude = the angle A P B on the fictitious sphere.

4th. Take the difference A b_1, expressed in seconds, in the latitudes of the stations A and B or b_1, and convert it into feet by the approximate radius previously used, and then convert the distance in feet so found into seconds of the earth's surface on the meridian,† which will give the true difference of latitude between those two points on the assumed figure of the earth.

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* Colonel Yolland remarks, "It was found that the normal, or radius of curvature perpendicular to the meridian for the latitude of the given station, must be used in the determination of that of the second station, and the normal for the latitude of the second in the determination of that of the third, and so on, instead of using any *approximate radius*. It was also seen that, in addition to obtaining accurate results, the calculations might be materially abridged by using the normal, as it then became unnecessary to convert the difference of longitude on the assumed or fictitious sphere, to the corresponding difference on the spheroid, in consequence of the difference of the logarithms of the normals of the stations A and B on the spheroid being nearly identical with the difference of the logarithms of the cosines of the latitude of B on the fictitious sphere and on the spheroid, and hence that the angle P, as found in the third step, gave at once the difference of longitude, without working out the length of the arc of parallel B b_1; thus saving the labour of taking out all the logarithms and natural numbers required for the fifth step of the process, which, when great accuracy is required, is a most tedious and troublesome computation. But this step cannot be omitted if any other *approximate radius* be substituted instead of the normal for the latitude of the station A."

† The length of the radius, in any circle, is equal to the length of 57·2957795 degrees measured on the circumference of that circle; hence the radius of curvature being known, the length of the degree can be found. It will facilitate computations if before commencing them Tables be prepared of the Arithmetical Complements of the Logarithms of the number of feet in a second—1st, on the meridian; 2nd, on the perpendicular circle; and 3rd, on the circle inclined 45° to the meridian—for every 10′ of latitude within the compass of the Survey. Tables of this kind have been computed at the Ordnance Map Office, for the latitudes in Great Britain and Ireland.

5th. Then compute $B\,b_1$ in seconds $= P \times \sin.\ b\,P$, and convert this value into feet with the assumed approximate radius, and again into seconds of longitude, by using the spheroidal radius of parallel for the latitude of B or b_1; in other words, convert the length of B b_1 from feet to seconds of longitude, by dividing by the radius of curvature perpendicular to the meridian for the latitude of B × the cos. of the latitude of B × sin. 1″.

$$\text{6th.}\quad \text{Tang.}\,\frac{PAB+PBA}{2} = \frac{\text{Cos.}\,\frac{PA-PB}{2}}{\text{Cos.}\,\frac{PA+PB}{2}}\cdot\ \text{Cot.}\,\frac{APB}{2},$$

from which $PAB+PBA$ are obtained, and by subtracting the given angle, PAB, the required azimuth of the first station at the second is found $= PBA$.

It is in the verification of the results obtained by the above formulæ that the zenith distances obtained by the sector are used.

When the length of an arc of a great circle is to be measured on the earth's surface, the amplitude of the celestial arc of meridian is obtained by means of the sector. The line selected for the terrestrial measurement should be such as to give no cause to apprehend inaccuracy through irregular local attraction. A series of principal triangles is carried along the line so selected, and it is advisable to verify the work by measuring as a base a side of one of the terminal triangles. The triangles having been computed, and the bearing of their sides from the meridian or its parallel being known, the distances on the meridian may be found by right-angled spherical trigonometry, and the sum of these distances is the $\left\{\begin{matrix}\text{length}\\ \text{measure}\end{matrix}\right\}$ of the required meridional arc.

By a similar process, the length of the arc of a great circle perpendicular to the meridian may be obtained, and from it the length of the degree of longitude at any latitude on the measured arc.*

The computation of distances for the detail survey from the secondary triangulation.—If the grand triangulation have been properly executed, the sides of the great triangles will form so many checks on the minor distances to be computed from the secondary triangulation, that the risk of error will be very small indeed; and, should an error occur, it cannot cause more inaccuracy than the misplacement of one or two points. In theory, the rules which have been mentioned as applied for the computation of the greater triangles are equally applicable to that of the less; but as the distances become shorter, it will be found that the necessity for taking into consideration the figure of the earth becomes less apparent, and when the triangles at length become very small, the spherical excess is scarcely appreciable, and they may be solved by plane trigonometry. The apportionment of the error of observation among the three angles should, however, always be made according to the rule above given, whether the triangles be large or small.

Perambulation and notation of public boundaries.—Before commencing the detail survey of a district, it is necessary to ascertain and shew on a skeleton map the exact line of such public boundaries as are to be delineated on the finished plan, in order that the person in charge of the surveying party may take care that all parts of it, whether indicated by easily recognisable objects, such as hedges, walls, streams, &c., or following a line undefined on the ground, shall be precisely surveyed, and that the correctness of the map shall not afterwards be disputed.

The perambulator should be instructed by a person well acquainted with the

* The length of the degree of longitude is found by multiplying the degree of the perpendicular circle by the cosine of the latitud

boundary to be noted; and this person should be appointed by the local authorities, or delegated by the persons most interested in the just definition of the boundary; and when there are conflicting interests separated by the boundary, each interest ought to be represented by one or more persons.

The perambulation is commenced at some remarkable or well-defined point; and a series of straight lines passing as near as possible to the actual boundary and parallel to its general direction, measured with the chain, and offsets taken from them to all the curves and angles of the boundary. When a trigonometrical station, or some remarkable object sure to be accurately fixed, is within reasonable distance of the chained lines, it is expedient to take an offset to it.

The boundary remark-book is kept much in the same manner as an ordinary content field-book. The names of proprietors on either side of the boundary are shown in it, and remarks setting forth all customary or legal rights touching the ground over which it runs should be entered. These remarks should be full and precise.

In general, county or parish maps can be procured, from which to construct the skeleton map, and in such cases only the measurement should be conducted as above described. But where no moderately good map is available, the perambulator must traverse the boundary with the theodolite; and the skeleton map will be made entirely from his work.

When there is a disagreement as to the right direction of the boundary line, which disagreement cannot be adjusted on the ground by the umpires or meresmen, the perambulator will ascertain the lines according to each claim, and note them in his book; and he will, further, draw up a report of the claims and arguments on both sides, and of the names of such witnesses as can speak to the matter, in order that the proper survey officer may—if he shall fail in inducing the parties interested to bring their differences to issue—be enabled to collect information whereby to decide the fair line for the purposes of the survey.

The skeleton map exhibits simply the line of boundary, and the objects distant a few feet on each side of it. The ordinary distances and notes from the boundary remark-book are shewn on it by figures and abbreviations, and particular remarks are either written on some part of the map near to the portions of boundary to which they refer, or detailed on a separate paper, and referred to their proper positions by a mark or letter. The scale for these maps, as used on the Ordnance Survey of Great Britain (it is found very convenient), is 12 chains to the inch.

Detail Survey.—On entering on the survey of a district, the superintendent of surveyors is supplied with a rough diagram of the points fixed by the secondary triangulation (but shewing no distances nor angles), and with the boundary sketch (or skeleton) maps belonging to his work.

He arranges his triangles for survey with a view to local convenience, taking care, however, that their angles are not extremely obtuse nor acute, and that their sides are not very much disproportioned. Having done this, he allots a triangle to each surveyor of his party. The surveyors in any two adjacent triangles arrange between them which shall measure their common line. Each then proceeds to measure the sides of his triangle, and then divides and measures the interior by such lines as are best calculated for obtaining quickly and accurately the detail within it. For the scale of six inches to a mile, on which the maps of the Ordnance Survey are now drawn, no sketching whatever is allowed, neither is the direction of any line allowed to depend on an angular bearing, but every line is adequately checked by other lines.

It was for a long time the practice to level the sides of the triangles, then to chain to the surface of the ground, and reduce the measured length to the horizon. But of

late it has been found equally correct and more expeditious to dispense with the levelling, and to cause the surveyor to stretch his chain always, as near as he can judge, parallel to the plane of the horizon; and then to find, by a plummet let fall from any of its divisions, the distance on the inclined surface. Thus the field-book requires no correction.

A chain's length should be laid off from a standard at some convenient place where the party assemble before going to work, and every chain tried, and corrected, if necessary, in the morning before it is used. The adjustments of the theodolites and levels should, in like manner, be tested every day before they are used.

Every surveyor dates his day's work in the field-book, and at some convenient spot on every page collects the total length of lines and offsets contained in it. The amount is carried over and added to that of the next page, and so on, to the end of the day's work.

All erasures in the field-book with a knife are forbidden.

No work is allowed to be entered in pencil.

For the six-inch to a mile scale no offset may amount to a chain in length, and for other scales the limitation should be proportional.

The average daily progress of a good surveyor in England, surveying for the six-inch to a mile scale, is—

With one Chain-man.

Close large village	about 5 acres.
Villages and surrounding fields, &c.	,, 14 ,,
Close country, gentlemen's houses and demesnes, &c. .	,, 20 ,,
Medium country, ordinary fields, and scattered farms . .	30 to 32 ,,
Open moorland with roads, streams, boundaries, car-tracks, &c. (*No* fields.)	—— 55 ,,

Traverse surveying, and the determination of distances by the small instruments, are never resorted to when the triangular and actual measurement can possibly be applied.

The system here described can be carried out in the survey of a large town. The directions of all the lines are ascertained by an instrument, and marked on the walls and pavements for the guidance of the surveyor. This should be done by the non-commissioned officer in charge or some trustworthy person. Where the direct line is impracticable, the surveyor measures on a parallel line. If to be laid down on a large scale, such a survey will require very great care. Liverpool was surveyed in this way for the scale of five feet to the mile. Different officers may prefer different modes. Manchester, for instance, was divided into blocks of houses, so that the bounding lines of each block might fall in a street or alley, and thus be comparatively convenient to measure.

The division of the survey into sheets or plans and the means of preserving coincidence of the common lines.—As a boundary line for a plan or division of the map, a series of sides of secondary triangles is preferable to a townland or parish boundary; because any two sheets have thus for their common boundary straight lines, and moreover, the extremities of these lines are trigonometrical points, which can be laid down with equal exactness on both sheets. The detail of the country on the two sides of these common lines will thus be plotted either by different persons or at different times; and to insure exact coincidence of all the points, the line, with a small extent of the detail on one side of it, is first traced from one of the plans, and the trace is then applied to the same line on the other plan; if any disagreement be perceived, the cause is immediately sought for in the field-books and plotting, and adjusted. Supposing the common line to separate not only two plans, but likewise

the work of two different officers, stationed in different places, the trace with the work of one of them shewn, say in blue, may easily be transmitted to the other, who will trace his side in red or some other colour : the smallest difference thus becomes apparent. The arrangement here described has reference only to the *construction* of the maps ; of course when they are printed, it will be on sheets containing each an equal area.

The search after names, and determination of their orthography.—According to the scale of the map, it must be determined, before beginning to draw, of what objects it will be practicable, consistently with a due regard to clearness, to insert the names. An uniform rule must of course be followed throughout the work. The perambulators and surveyors should be ordered to collect as many local names as they can without hindrance to their other duties, and to forward with their field-books a list of the names and a brief description of the spaces or objects to which they belong. These lists serve as guides to the persons sent expressly to ascertain correct names and orthographies. Land-owners, clergymen, and such other persons as from professional opportunities or antiquarian or local knowledge are competent to give opinions on these points, will be requested to write and sign what they consider necessary touching the orthography, derivation, and application of names. From records such as these, a choice of the mode of spelling will, in most instances, be easily made ; but in some cases it will be necessary to refer to men who have studied the ancient and provincial dialects of the districts in which the names occur.* Besides the objects which belong to the present age, it is highly desirable to shew, on a general map, remains and sites, also battle-fields,—spots where interesting events have occurred, &c.

The plotting of distances, and detail on paper.—The trigonometrical points should be laid down on the sheet to be plotted, by a non-commissioned officer or superior draftsman, who will see that each point is in its exact position with relation to all the other points on the sheet. The plotting will need very little description, as so far from being more difficult than in ordinary surveys, it will be found, by reason of the trigonometrical system according to which the survey is made, the easiest possible. There is no need of the protractor—all the lines fit into their places and check each other, and the detail is laid down very simply.

The plotter should be required to bring to the notice of the superintendent all errors in the field-book, and all cases where the surveyor has departed from the regulations, in the too great lengths of his offsets, in not sufficiently checking his lines, in making erasures in his book with a knife, &c.

The examination on the ground.—After the detail of a plan has been plotted in pencil, it is traced off in portions convenient for a sketching portfolio, and given to field sketchers, or examiners, to be taken to the field and rigorously examined, and, if necessary, corrected. The examiner should always have a chain and offset-staff with him. He, besides ascertaining the accuracy of the trace, shews on it the detail in its proper characters, and gives full information to the draftsman, who is to pen in and ornament the plan.

The drawing, lettering, and ornamenting.—These, like the plotting, are operations so well understood, that it is unnecessary to say much here concerning them, except as regards the system, according to which, in extensive operations, they ought to be regulated. The features of the ground, on the Ordnance Map, used till very lately

* The writer would lay stress on the propriety of employing, for the collection of orthographies, men fitted by education and intelligence for the duty : the attempt to do the work *mechanically*, by employing illiterate persons guided by fixed rules, will be found very unsatisfactory, and, in the end, far from economical.

to be shewn by portraiture on the 'light and shade' principle, very skilfully executed, and giving the maps a beautiful appearance. This mode has, however, now been changed for the exhibition of the levels, by means of horizontal contours at 25 feet vertical intervals—a style less appreciable by the eye, but having the advantage of giving the accurate altitudes and slopes of the country, whereby the practicability, or proper direction of roads, canals, railways, &c., may be readily decided on; and thus forming a most important and valuable aid in the projection of public works. Certain symbols (see 'Topographical Hieroglyphics,' vol i. part 2) should be adopted for the representation of objects of frequent occurrence. The systematic use of the different print hands, in the names, may be made a means of indicating to some extent the nature of the object. Thus the names of counties, ridings, hundreds, parishes, townships, &c., should be written always in uniform characters; churches, gentlemen's seats, demesnes, antiquities, works of art, &c., the same; and ranges of hills, single features, &c., each kind in appropriate type. The ornamenting should be arranged with a similar view; and roads, woods, sands, ravines, parks, pleasure-grounds, &c., be all uniformly represented.

Contouring is already described in vol. i., and Levelling in vol. ii.

The computation of areas.—When the areas of the public divisions of a country are required from a trigonometrical survey, it will be advisable to ascertain them in two different ways—first, by computing the areas of the triangles whose sides most nearly coincide with the areas of such divisions, and adding or deducting the irregular figures which may be interposed between the boundary and the sides of the rectilinear figures. This computation ought to be made in duplicate; and, to prevent the risk of collusion, it is better that the two persons who make it do not reside in the same town. Their computations can afterwards be compared, step by step, and disagreements be investigated and adjusted. The other way is by measuring with a computing scale or other instrument the different areas on the plan or map. This mode is of course less accurate than the former, but it forms an excellent check, and should not be omitted.

Engraving, printing, and publication.—On the Ordnance Survey of Great Britain the maps are engraved and printed under the superintendence of the Director. Ingenious machines have been invented for laying down the trigonometrical points on copper, and for ruling the lines of even shades such as are used for buildings. The last improvement in these was made by Colonel Yolland, R.E. It is unnecessary in this place to give a description of these operations. For the sale of the maps, agents are selected by the Ordnance in the metropolis and principal towns, to whom 25 per cent. profit is allowed on the price paid by the public. The maps hitherto published on the scale of 1 inch to a mile have been of different sizes in different parts of the kingdom; and it is obvious that the quantity of labour spent in this preparation cannot be the same for all, even if there were no variation in size. They were, therefore, originally published each at a cost proportioned to the expense of preparing it. Since, however, the art of electrotype has become available for the renewal of the plates, it has been determined that 2*s.* the sheet, or 6*d.* the quarter-sheet, shall be the price for all the work. It is moreover determined that the sheets on this scale shall henceforth contain a fixed area of 864 square miles.

The sheets on the scale of 6 inches to the mile contain each 24 square miles, and are published at the price of 5*s.* each, but it is believed that a reduction of this price is contemplated.

FORCE AND ORGANIZATION OF THE ORDNANCE SURVEY OF GREAT BRITAIN AND IRELAND.

The force employed on the Ordnance Survey of Great Britain and Ireland is partly military and partly civil. The Ordnance Map Office, or office of the chief officer, which is the head-quarters of the Department, is stationary, and at present fixed at Southampton. Besides the business belonging to the general superintendence, and the diagrams and computations of the trigonometrical department, the engraving and printing for Great Britain are executed here; and here, too, are the principal stores of the Survey. While the survey of Ireland was in progress, there was a head-quarter office in Dublin; and though Southampton is now the head-quarters for both islands, the engraving and printing of the Irish plans are still executed in Dublin, and the documents and plates of the Irish Survey are there preserved in a fire-proof building. The Officers in the field hire temporary offices in towns convenient for their work. Each Officer constructs in his own office the maps of the country surveyed by his field parties, and, when they are finished, transmits them with the field-books, sketch maps, and all documents connected with them, to head-quarters to be engraved. Thus there is a field and an office force attached to each division.

Direction.—An Officer of the Royal Engineers, receiving his appointment and instructions from the War Department, through the Inspector-General of Fortifications, conducts the Ordnance Survey with the official style of Director. He regulates the whole of the operations connected with the undertaking, from the measurement of the base to the completion and publication of the maps. He commands the military companies employed on this service, and controls the civil branch in all matters affecting the work. He demands from the Inspector-General the number of Officers required to assist him, according to the duties in progress and the proficiency of the non-commissioned officers and other assistants. The interior economy of his department is ordered entirely by his discretion, his expenditure being limited by an annual parliamentary grant.

The Organization is throughout according to a military principle, and though the assistance of civilians is largely made available, it is simply to serve, so to speak, as muscles for the military skeleton. No branch of the duty, however inferior, is performed entirely by civilians or without the supervision of some responsible soldier; and the conduct of all the operations is within the control of the Mutiny Act and Articles of War.

Assistant Officers have charges assigned to them in the different departments of the Survey—

One or more being employed to assist the Director;
One, at the least, to direct the trigonometrical operations;
One for the boundary department;
One for contour levelling;
One for each division of the detail survey.

Their number is by no means constant, but is regulated by the extent of ground under survey, and by the degree of proficiency of the non-commissioned officers. For instance, till very lately, one Officer, if not two Officers, was always present with each great instrument; now, the non-commissioned officers are so well instructed that they can observe as correctly as their superiors, and the constant presence of an Officer is no longer necessary.

The military force is divided into sections, each of a strength sufficient for the entire direction and supervision, and for the partial execution of the duty allotted to it. The Captain and Subalterns of a company are very seldom stationed in the same place, and the strength of the detachment with each Officer is proportioned not to his rank, but to the exigencies of the service on which he is employed.

The non-commissioned officers ought to be most carefully selected, and employed with regard to the direction of their respective talents.

The responsible offices are all filled by soldiers, no civilian being responsible for more than his individual labour.

Each soldier employed on the survey is allowed working pay at a rate fixed by the Director, according to his acquirements and industry; and for the satisfactory performance of duties requiring management and industry—such, for instance, as reflecting with the heliostat, piling hills with judgment, &c., it is customary to allow special rewards.

It is advisable that the soldiers should be instructed in the duties of as many branches of the work as possible, that they may be available whenever the service may most require them.

The civil branch works entirely under the direction of the military; and, speaking comparatively, its duties may be styled mechanical. The labours of the civilians are constantly overlooked, and their duties assigned daily. It is expedient, moreover, to guard against collusion, that each civil assistant should comprehend only his own particular duty, be it surveying, plotting, drawing, or other service. This policy is rendered necessary by the extremely slight ties by which civilians are bound to the service. They receive their wages weekly, and although it is expected that they give a month's notice before quitting their employment, there is no power to prevent their doing so at any minute when they may be so inclined.

Accounts.—Each Officer is furnished monthly with an imprest to meet the probable expenses of his division or party. He distributes the pay of the civilians and the working pay of the military, and makes the disbursements necessary for the contingent requirements of his division, taking proper vouchers, and quoting in each case an authority for his expenditure.

Every division having commonly several small detachments in the field, the payment of each detachment is necessarily made through the non-commissioned officer in charge of it.

Once in a quarter each Officer submits his accounts to the Director, who, having examined and approved of them, forwards them to the Surveyor-General of the Ordnance.

Chain of responsibility.—Every party, however small, is under the charge of either a non-commissioned officer or private of the Royal Sappers and Miners, who is responsible that the work is carried on according to orders, and that every precaution to prevent negligence or deception is taken.

In the office, likewise, a non-commissioned officer superintends each department of the work.

These report, either directly or through a senior non-commissioned officer, to the Officer of Engineers in charge, and, according to the latest arrangement, each Officer reports immediately to the Director.

DESCRIPTION OF COMPENSATION BARS (PAGE 579).*

Plate III. Fig. 1.—Diagram shewing the principle of the compensation bar.

$a\ a'$, Brass bar.

$b\ b'$, Iron bar.

$p\ q$, Steel connecting bar.

$c\ c'$, Brass bar, $d\ d'$, Iron bar } at the higher temperature of $62° + n°$.

$e\ e'$, Brass bar, $f\ f'$, Iron bar } at the lower temperature of $62° - n°$.

$a\ b\ n$, $a'\ b'\ n'$ } Position of the steel tongues at the temperature of $62°$.

$c\ d\ n$, $c'\ d'\ n'$ } The same at the temperature of $62° + n°$.

$e\ f\ n$, $e'\ f'\ n'$ } The same at the temperature of $62° - n°$.

n, n' } The points of intersection, or compensation.

Fig. 2.—Plan of the compensation bar, lying in its deal box, supported upon brass rollers, fixed into the bottom of the box at one-fourth and three-fourths of its length; the parts being free to expand from or contract to the centre: the brass nozzles, which protect the projecting part of the tongues, are also shewn in this figure; likewise the longitudinal spirit-level and scale, and the small brass cross-pieces for steadying the bars by preventing any sudden jar from striking them against the lid of the box.

$a\ a'$, $b\ b'$, the compensation bars.

e f g h, the deal box.

$r\ r'$, rollers.

$o\ o'$, protecting brass nozzles.

$m\ m'$, cross steadying pieces.

$s\ s'$, two strong iron cylinders, uniting the brass and iron bars at the centre.

t, vertical brass stay, screwed to the bottom of the box, to prevent longitudinal motion.

l, longitudinal level.

$x\ x$, shewing the mode of attaching the level to the brass bar.

Fig. 3.—Mode of fixing the brass and iron bars together at the centre, and of preventing any longitudinal motion of the bars in the box: the longitudinal scale and level shewn on the left. (The whole on a larger scale than in fig. 2.)

Fig. 4.—Side elevation of the bar, resting upon its roller in the bottom of the box, and shewing the brass cross-piece between it and the lid.

Fig. 5.—Side elevation of the bar in the middle, where the brass and iron are screwed together, and shewing the vertical brass stay.

Fig. 6.—Plan of the steel tongue on which the compensation point is marked, and which moves freely upon two conical brass pivots, with steel sockets, through the middle of the brass and iron bars, near their extremities.

Fig. 7.—Oblique end view of the tongue, pivots, and brass and iron bars.

Fig. 8.—Elevation of the pivot, seen from the side of the brass bar, shewing the rear or root of the tongue.

Plate IV. Fig. 9 represents one of the compensation bars in its box, as used in the measurement of the base, resting upon two brass levelling tripods or camels,

* From an account of the measurement of the Lough Foyle Base, by Colonel Yolland, R.E.

each having a lateral or cross motion, and one having also a longitudinal motion; each tripod rests upon a trestle or three-legged wooden stool, which stands upon a triangular deal frame, supported horizontally upon the heads of three stout pickets, of length proportioned to the nature of the soil into which they are driven. At each end of the bar in the figure (which may therefore be considered as the first bar in a set) a compensation microscope is placed, resting in grooves upon a brass three-armed stand, screwed to the end of the box containing the compensation bar. Under each of the centre microscopes is shewn a register, technically called a 'point-carrier.' These point-carriers are of various constructions, principally made of cast iron, and of a triangular form at the base: in the middle is a brass cylinder, sliding vertically through a tube and rings, with clamps to fix at any height the adjustable plate or disc which it carries at top, and on which is engraved a fine dot on a silver pin: this dot is finally brought to exact bisection under the microscope by means of three screws which move the disc horizontally in any direction. On the top of the bar-box is shewn the end of the cross-level, and also the shutter of the glass window through which the longitudinal level is observed during the measurement.

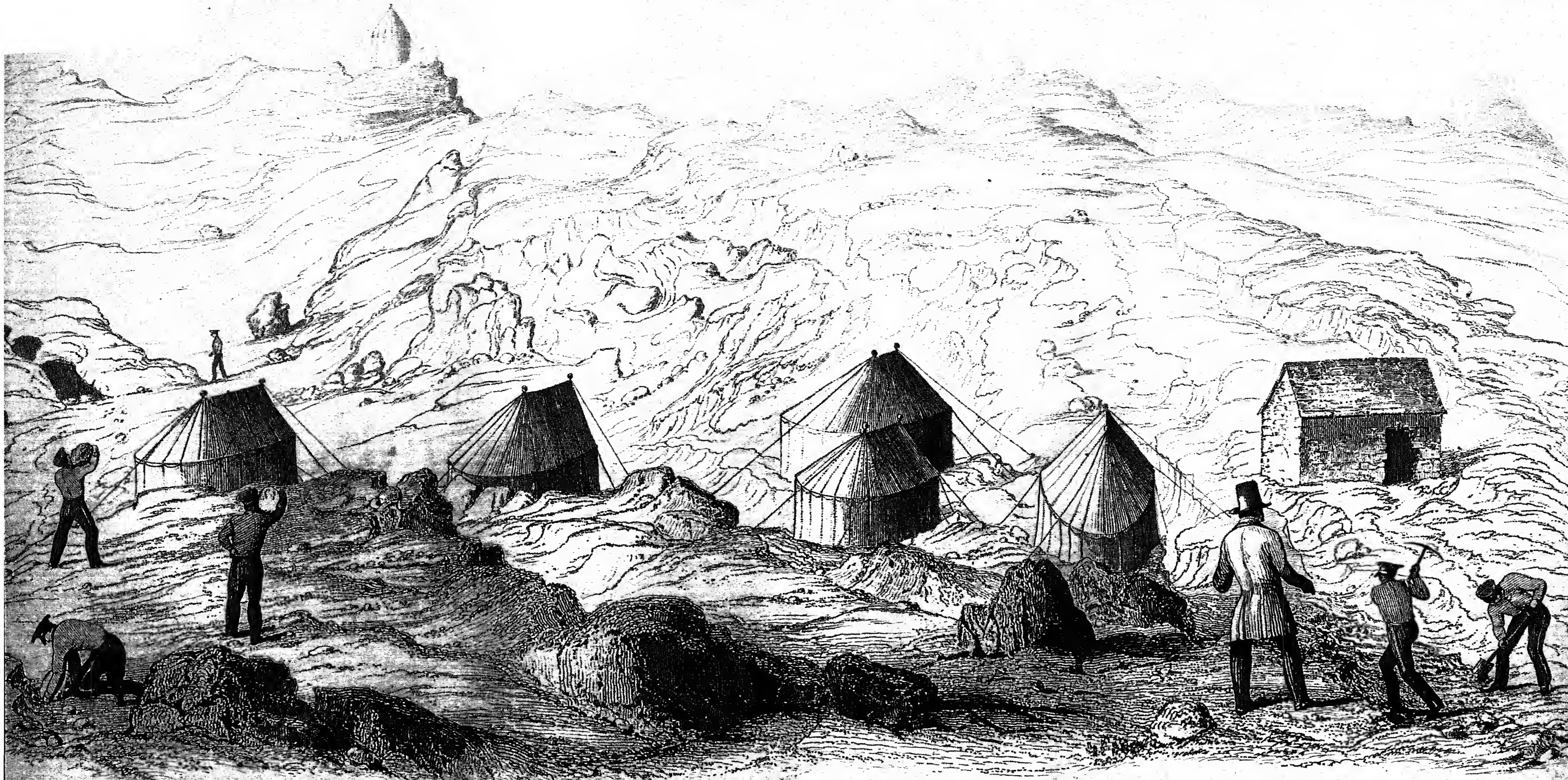
L L, Brass levelling tripods.
T T, Wooden trestles.
R R, Triangular deal frames.
P P, Wooden pickets.
C C, Clamping plates,
M M, Compensation microscopes.
Y Y, Registers, or point-carriers.
w, Shutter of the glass window over the longitudinal level.
v. Cross-level.

SWIMMING.*—It is scarcely necessary to prove that this art is useful to a soldier; but we may mention the brilliant feat of Captain Guingret, at Tordesillas, in November, 1812, who swam across the rapid Duero, with 60 gallant Frenchmen, pushing in front of them a small raft bearing their arms and clothing, and after storming a tower defended by the Brunswickers, opened a communication over the bridge: from this it will be evident that if soldiers are able to swim, they can rapidly effect the passage of a river, which may be of vital importance, and would be impossible otherwise; and when it is considered how often British troops are exposed to drowning by shipwreck or by the upsetting of boats, it appears advisable to give them every facility for acquiring the art, particularly as the practice of it tends so much to promote cleanliness and health.

As the human body is lighter than water, there are but few men who cannot be taught to swim; and if an instructor were appointed in each regiment, a large number of soldiers might soon learn: they could go through the *motions* even in a room by resting the breast upon a board suspended from a beam, or in a bath, supported by a strap passed under the armpits; and if arrangements be made for rescuing those who may get out of their depth, they could practise safely at most stations.

To swim on the breast, or in the ordinary way, it is necessary to imitate the motions of the frog; each stroke is made by first bringing the palms of the hands nearly together before the chest and throwing them forward with the fingers pointing to the front, then separating the hands so as to make a stroke outwards with the fingers extended close together, and finally bringing them in front of the chest again to make another stroke as before, at the same time kicking out behind, so as to make a steady simultaneous effort with both legs and arms, and keeping the head back so as to enable the swimmer to breathe freely.

* By Colonel Bainbrigge, R.E.



CAMP OF THE PARTY EMPLOYED ON THE ORDNANCE SURVEY ON CREACH BAIN, ARGYLLSHIRE.

London, John Weale, 59, High Holborn, 1851.

J. W. Lowry fc.

SKETCH SHEWING THE MODE OF PROCEEDING IN MEASURING THE LOUGH FOYLE BASE.

nance Map Office London, John Weale, 59, High Holborn, 1851. J. W. Lowry.

Fig. 1.

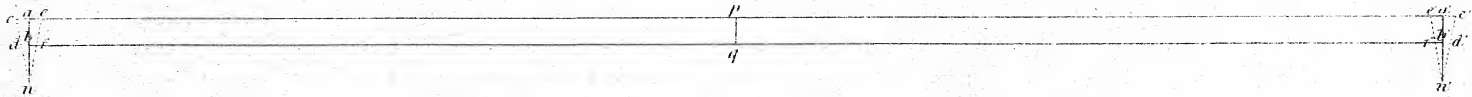


Fig. 2.

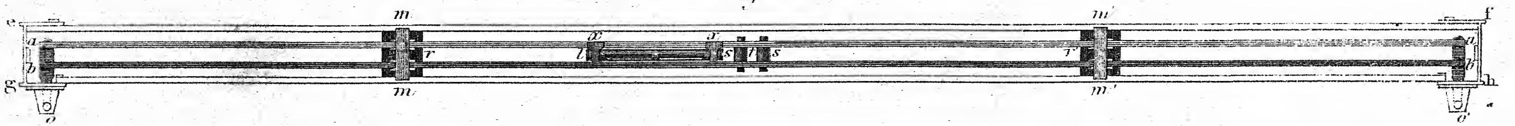


Fig. 3.

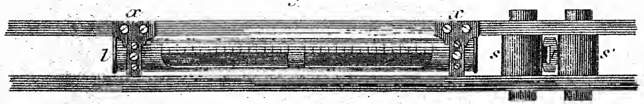


Fig. 6.

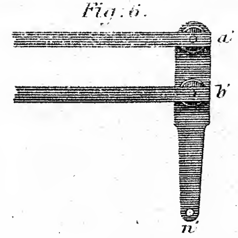


Fig. 10.

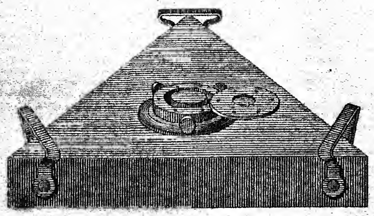


Fig. 4.

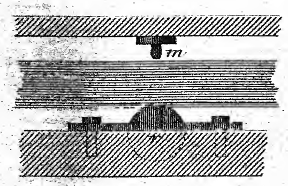


Fig. 5.

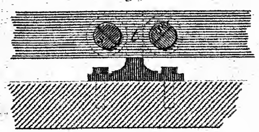


Fig. 7.

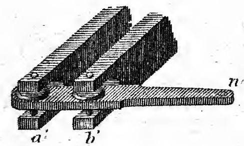
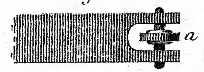


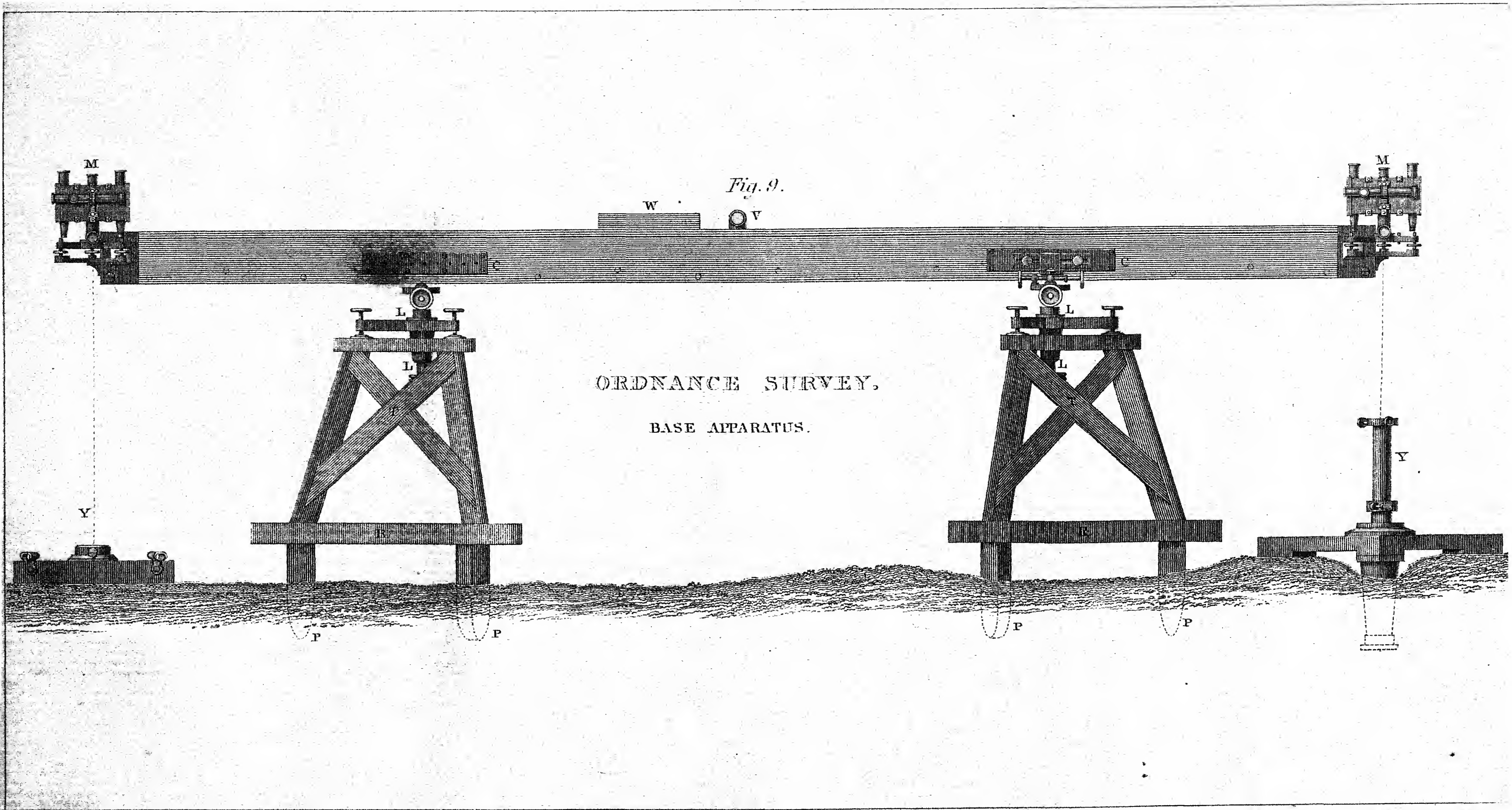
Fig. 8.



ORDNANCE SURVEY — BASE APPARATUS.

Ordnance Map Office

London, John Weale, 59, High Holborn, 1851.



J. W. Lowry sc.

Ordnance Map Office

In swimming long distances it is advantageous to rest the limbs by swimming on the back or side: in the former case it is only necessary to kick out with the legs, and in swimming on the right side a circular stroke is made with the right hand in front and with the left close to the side,—and the contrary in swimming on the left side: also rapid progress may be made by throwing forward each arm alternately, letting the hands fall edgewise into the water, and turning upon each side in succession as a stroke is made.

In order to *dive*, the head must be turned down, and the legs being thrown up, the body will sink, and can be propelled in any direction as in swimming on the surface: the eyes being kept open and objects distinctly seen under water, persons who have sunk can be searched for and pulled up, care been taken to avoid their grasp; and if they have presence of mind, they can, on reaching the surface, support themselves behind the swimmer by resting their hands on his hips whilst he advances towards the shore.

If letters, clothes, ammunition, the locks of muskets, &c., are required to be conveyed, it will be best to secure them on the head; but the proper buoyancy will be best preserved by carrying things under water attached to the back.

Though cramp is much feared, it seldom attacks people except when the water is cold, or when they have been a long time in it, and it generally goes off by lying on the back and stretching out the heel.

Swimming with a line is often required, when vessels are wrecked (as boats are often useless), to establish the means of escape, and also when it is necessary to cross rivers in advancing through an enemy's country, or in traversing a wilderness: this is rendered difficult by the weight of the rope causing it to sink, when the effect of the current upon it is increased, and it is liable to be entangled among rocks or seaweed; and as one man cannot support more than 50 yards of small rope, the swimmers must not be placed at greater intervals apart; and they should, when crossing a current, hold the rope with the hand on the side opposite to that from whence it flows, or, to give both arms perfect freedom, the rope might be hooked to a belt supported by the shoulders, and arranged so that it may be easily detached: it should of course be carried as much as possible with the stream, and care must be taken to pay it out with judgment.

To support the line, floats of cork or slips of light wood may be lashed to it, taking care that they are of such a form as will oppose least resistance to its progress; this result would be best attained by making the line itself buoyant, or by substituting for it an inflated tube of small diameter, formed of canvas, rendered air-tight: if only a small portion of this could be obtained, it should be attached to that end of the rope intended to reach the shore, for there the chance of a heavy line becoming entangled is the greatest, and by wrapping a few turns of such a tube round the body of each person who could not swim, or round mail-bags or other valuable packages, they could generally be floated ashore if guided by swimmers, as in cases of wreck the wind usually blows strongly towards the shore; also the boats might be rendered more buoyant by attaching it under their thwarts.

If the distance from the wreck to the shore is great, swimmers might perhaps derive aid from a small raft consisting of at least three short spars firmly lashed together, and having numerous ropes attached so that the men might take a turn with them round their waist, to prevent their being washed off; and this might be steered by hoisting a small but strong sail, but it would probably be stranded on outlying rocks or sand-banks, and the swimmers can then only advance unaided, or supported by corks, or light air-tight cases attached by straps passing under their armpits (for which purpose common square air-cushions strapped over the chest, and thus present-

ing only a thin edge to the front, have been found convenient) : as they approach the shore, if they cannot find an inlet among the rocks, they must make for a smooth beach, if possible, and the moment they find they can obtain a footing they should run on quickly, so as to get out of reach of the succeeding wave : a close-fitting flannel dress would not much impede them in swimming, and would be found useful to protect them from the effects of cramp, and of the wind on land ; and a light pair of shoes, which might be carried at the waist, would enable them to be of more service among rocks or flints.

By means of the small line which is first taken ashore, a stronger one may be hauled thither, and by passing it through blocks a constant communication may be established : in this manner great numbers of persons have been rescued from drowning.

T.

TACTICS OF THE THREE ARMS.

ON THE COMBINATIONS OF THE THREE ARMS IN THE COMPOSITION, FORMATIONS, AND MOVEMENTS OF ARMIES.*

"Placer les différentes armes selon le terrain, selon le but qu'on se propose, et celui que l'on peut supposer a l'ennemi ; combiner leur action simultanée d'après les qualités propres à chacune d'elles, en ayant soin de les faire soutenir réciproquement ; voilà tout ce que l'art peut conseiller ; c'est dans l'étude des guerres, et surtout dans la pratique, qu'un officier supérieur pourra acquérir ces notions, ainsi que le coup d'œil qui inspire leur application opportune."—*Jomini, Précis de l'Art de la Guerre,* chap. vii. art. 47.

Relations subsisting between the Combinations of the Three Arms and the Results and fundamental Conditions of Warfare.

The result of a battle is very materially affected by three things, which are in a great measure under control of the Generals who command, and exercise an influence which, if not independent of the courage of the troops engaged, is at least distinct from the influence which courage exercises in deciding the issue of the shock of armies.

These things are—

1st, The choice of the field of battle.

2nd, The disposition of the principal masses composing an army relatively to those of the enemy, and the manœuvres executed by them during the battle.

3rd, The manner of developing the different species of destructive forces made use of in warfare, through the agency of the cavalry, infantry, and artillery.

To a certain extent, the consideration of any one of these three things necessarily involves that of the other two, not merely from the necessity of viewing them together as concurrent causes concerned in the production of a given effect, but more especially from the ultimate connection and mutual relations subsisting between them.

Thus it is obvious that the relative importance of the three arms, and the order of their distribution in the arrangement of an army, must be essentially modified by the nature of the locality on which the army is to combat. Among rocks and thickets infantry is the best species of force which can act effectively ; on open plains cavalry may be considered the predominant arm ; and in the defence of defiles and the attack of posts artillery has the principal part to perform.†

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* By Colonel Robertson, of Her Majesty's 8th Regiment.

† The formation of troops and their preliminary dispositions depend much more on the

Omitting, however, all considerations both of particular localities and of particular orders of battle, certain general principles may be laid down for the combinations of the three arms, solely founded on the relations which subsist between the distinguishing peculiarities in the mode of development of their destructive forces, and the fundamental conditions of offensive and defensive warfare.

Rest, or the ability to maintain a position, is the essential condition of defensive combinations.

Motion, or the ability to advance, is the essential condition of offensive combinations.

In treating of the combinations of the three arms, the first thing to be done is, therefore, to consider how the development of the destructive power inherent in each is affected when subjected to one or other of these conditions.

In modern warfare there are four distinct methods employed for effecting the destruction or defeat of an enemy, viz.

1st, *The charge of cavalry.*

2nd, *The charge of infantry.*

3rd, *The fire of infantry.*

4th, *The fire of artillery.*

Of the Charge of Troops.

In estimating the effect of a charge on the combinations of the three arms and of the circumstances in which a charge is applicable, it is necessary to consider the obstacles by which the charging body may be opposed, and the results which it is capable of obtaining.

The obstacles by which a charge may be obstructed are—

Local impediments, whether artificial or natural, such as fortified posts, intrenchments, abattis, inundations, enclosures, rivers, thickets, swampy or rugged ground. These impediments may either be such as to render a charge altogether impossible, or they may be such as merely to increase the risk and difficulty attending its execution.

The particular consideration of this class of obstacles on military operations is treated under the subjects of Fortification and the choice of Positions.*

The fire of artillery and musketry is another obstacle which offers a formidable obstruction to the charge of every species of troops. The effect of fire in opposing a charge depends partly on its intensity and partly on its duration, that is, on the length of time during which the charging body is exposed to its action. This length of time is determined by the range of the projectiles and by the distance and rate of motion of the charging body: as these vary, so does the effect of this obstacle. The protection of fire cannot be always successful against a sudden rush; but a feeble fire may suffice to stop the advance of troops, if the distance they have to traverse be considerable and their rate of progression slow.

A natural obstacle, by impeding the advance of an attacking force, may so greatly increase the effects of the fire by which it is opposed as to render a charge impracticable, though neither the magnitude of the obstacle nor the intensity of the fire might have been singly sufficient to stop the onset of resolute men.

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nature of the ground than on any other consideration whatever. The strength of a position compensates for numerical weakness.

Defiles in front of an army render superfluous a portion of the means of defence, and increase the difficulties of developing the means of attack. As regards details, the slightest consideration, and frequently instinct alone, is sufficient to render evident those modifications which the formations consecrated by usage must undergo in order to adapt them to particular localities.—*Marmont, Esprit des Institutions Militaires*, part iii. chap. 8.

* See 'Fortification, Field,' and 'Position, Retrenched.'

The nature of the result to be derived from a successful charge depends on the relation which subsists between the force that attacks and that against which the attack is directed.

(1.) When both forces are of the same kind, if the troops composing each be equal in numbers, strength, courage, and equipment, the result of a collision must necessarily be uncertain, and will very probably be indecisive.

If the force attacked be inferior in any of these points, it may, by retiring, always avoid a collision, and escape without sustaining any serious loss.

When, therefore, the contending forces are of the same kind, all that can generally be effected by a charge is to drive the enemy from a position.

The result of a successful charge is in this case limited to the gain of a position; the destruction of the troops defending it, if effected at all, must be accomplished by other means.

The expediency of charges of this class must in each particular case be principally determined by a consideration of the relative numbers and comparative quality and efficiency of the opposing forces.

(2). When the attacking force possesses in close combat a natural physical superiority over the force attacked, the utter destruction of the enemy may be calculated on as the probable result of a successful charge. The certainty of this result, and consequently the expediency of charges of this class, depends entirely on the possibility of bringing the charging body into contact with the object of its attack without its suffering a greater loss than will be repaid by the destruction of the enemy.

In each particular case this will be determined by a consideration of the description of natural obstacles to be surmounted, and of the intensity of the fire to be encountered.

Of the Charge of Cavalry.

Rest is incompatible with the action of cavalry; that is to say, a body of cavalry, when assailed, must either advance or retire; by simply remaining firm, it cannot either maintain a position or inflict any injury on an enemy.

Marmont says, "Close combat and hand-to-hand struggles are the objects of the institution of cavalry.

"It ought to thrust home the sword's point on the enemy, to crush and overwhelm his ranks by its shock, to annihilate his shattered forces by a swift pursuit.

Esprit des Institutions Militaires, part ii. sect ii.

"To pursue the enemy is its habitual office; for it is rare that a collision takes place at the instant of meeting: the less confident of the two parties stops and betakes itself to flight."*

Unless it be possible to bring cavalry into absolute contact with an enemy, it cannot be made available for its destruction.

The ability to advance is therefore the essential condition on which depends the development of its destructive power.

Charges of cavalry may be resorted to in order to effect three different objects:

1. *To drive another body of cavalry from the field.*
2. *To destroy infantry.*
3. *To seize batteries of artillery.*

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* The principal uses of cavalry are—to prepare the way for victory, to render it complete by the capture of prisoners and trophies, to pursue the enemy, rapidly to succour a menaced point, to complete the overthrow of infantry previously shaken, and finally, to cover the retreat of infantry and artillery.

The reasons are therefore apparent why an army deficient in cavalry rarely obtains any signal success, and why it experiences such difficulties in its retreats.—*Jomini, Précis de l'Art de la Guerre*, chap. vii. art. 45.

(1.) A body of cavalry may by a charge compel another of inferior force to fly from the field, and this result will probably be obtained without a collision taking place, —consequently, without any risk or loss being incurred by the charge.

In order to cover the advance or retreat of infantry, it is sometimes expedient for one body of cavalry to charge another of equal or even superior force. When this happens, a collision ensues, the result of which must depend on the courage and strength of the respective combatants. The expediency of risking a contest of this sort depends on the importance of the object to be obtained by preserving the infantry from attack. It is sometimes essential to the plans of a General to risk the sacrifice of his cavalry for the preservation of his infantry.

(2.) The success of a charge of cavalry against a body of infantry hinges on the possibility of the cavalry breaking the ranks of the infantry.

If by its fire and by its bayonets the infantry cannot resist the charge, its destruction is inevitable: retreat will not secure its preservation.

Without venturing to affirm that it is physically impossible for cavalry to break an infantry square, experience certainly authorizes the assertion, that the result of a charge of cavalry against infantry in good order, and occupying a fixed position, is very likely to prove a failure.*

To insure signal results from a charge, infantry should be attacked either when their ranks are in some degree broken and disordered, or when engaged in the execution of a movement, and unable to assume a formation of defence.

When infantry are regularly formed for the defence of a fixed position, previous to a charge of cavalry, a fire of musketry and artillery should be employed to break their formation and diminish the intensity of their fire.

It was thus that Napoleon conducted his attack on the Prussian army at Jena. At Borodino also the fire of infantry and guns prepared the way for the successful efforts of the French cavalry.

In resisting an attack, or opposing a pursuing force, opportunities frequently occur for cavalry to charge successfully without the co-operation of the other arms. Thus at Marengo, the pursuing columns of the Austrians were overthrown, and the tide of victory turned by a sudden and vigorous charge of French cavalry.†

On account of the inability of infantry in movement to resist the attack of cavalry, it may perhaps be concluded that the opportunities for the effective employment of cavalry against infantry are greater when the cavalry is employed in defensive combinations against a force moving to the attack, than when it is employed in offensive combinations against a force occupying a fixed position.

(3.) When it is necessary to seize a battery by a charge, cavalry, if the ground be favourable for its action, is the species of force best adapted to execute this service.

Though the bulk of a body of cavalry considerably exceeds that of a body of infantry, yet the rate of motion of cavalry is so much greater than that of infantry, that in traversing equal spaces the former will suffer much less than the latter.

At the battle of Jena, the capture of a battery was the object of a brilliant charge of a portion of the French cavalry.

When cavalry are employed to carry a battery, a body of infantry should follow closely for the purpose of securing the guns.

* It is admitted that a general attack of cavalry against a line of infantry, in good order and at a certain distance, cannot be successfully attempted unless supported by infantry and a very numerous artillery. We have seen how severely the French cavalry suffered in consequence of their acting contrary to this rule at Waterloo, and at Kunersdorf the cavalry of Frederic experienced the same fate.

† The Austrian cavalry having left the field.—*Editors.*

Of the Charge of Infantry.

A charge of infantry may gain a battle, but it cannot destroy an army.

The object of a charge of infantry is either to capture guns or to dislodge another body of infantry from a position.

(1). When the capture of guns is the object of the charge, success depends on the charging body persevering in its advance until it reaches the battery. If this can be effected, an absolute result will be obtained. The risk of failure will be in proportion to the distance of the battery and the number of guns of which it is composed.

No extraordinary effort is required for infantry to seize a few detached guns; but when the fire of many guns is concentrated to oppose its attack, the havoc created is so dreadful that the most courageous infantry frequently fails in the attempt to carry a powerful battery.

At the battle of Leipsic, on the afternoon of the third day, the Allies concentrated on the French army the fire of 800 guns, disposed in a semicircle of two miles in extent. For four hours the French troops sustained, without flinching, this tremendous cannonade. During that period, columns of infantry repeatedly rushed forward to carry the batteries; but, as soon as they arrived within range of grape, they were swept away, and their shattered remnants driven back in confusion.

(2.) When one body of infantry charges another, excepting in affairs of posts, a collision seldom or never takes place.*

The immediate result of a charge of infantry is simply to cause the enemy to abandon a position. Nor can this result be obtained, even by the aid of great numerical superiority, without the attacking force sustaining a severe loss from the fire of their opponents. In this respect the attack of infantry on infantry differs materially from that of cavalry on cavalry.

Of Fire in General.

Although motion is totally incompatible with the action of artillery, and very unfavourable to the development of an effective fire of musketry, yet both species of fire are available as well for the purposes of attack as for those of defence.

That terrible iron shower which shatters the ranks of an attacking column and forbids it to approach a position, is equally efficacious when employed to sweep away the battalions which defend it, and to compel them to fly from its far-reaching fury.

In considering the effect of fire as a means of offence, it is, however, important to remark, that the troops against whom it is employed may by retreating neutralise its power as a destructive agent.

The assailants may indeed pursue, but it is not possible at the same time to march and to fire with effect.

Hence, while the retreat may be uninterrupted, the pursuit must consist of alternate advances and halts, and the pursuers will necessarily be distanced before they are able to effect the complete destruction of the beaten force. It may therefore be laid down as a general rule, that in offensive operations great and decisive results cannot

* In actual warfare I have never seen combats of infantry otherwise conducted than by battalions deployed beforehand, who commenced firing at first regularly by companies, afterwards independently by files, or else by columns marching boldly against the enemy, who either gave way without awaiting the shock of the columns, or repulsed them before the moment of contact; it might be by the effect of their fire: it might be by their firm demeanour, or finally it might be by rushing forward to meet their assailants. Scarcely anywhere but in villages or defiles have I seen actual conflicts between columns of infantry, the heads of which struggled by the push of bayonets; never in the field of battle have I seen anything like this. —*Jomini, Précis de l'Art de la Guerre*, chap. vii. art. 44.

be obtained without the aid of cavalry, and that troops, if assailed only by infantry and artillery, may usually effect a retreat.*

The cases which present exceptions to this rule are those in which it is possible to concentrate a powerful fire on a mass of men entangled in a defile or other situation where they cannot escape from its effects. Thus, at Rivoli, an army was precipitated into a defile and destroyed by musketry; and more recently some batteries of horse artillery made frightful havoc among the masses of the Sikh army while endeavouring to escape across the Sutlej, after being driven from their intrenchments at Sobraon.

Of the Fire of Infantry.

The destructive effect of fire is modified by two classes of circumstances,—by those circumstances which affect the facility of its concentrated application, and by those which affect the intensity of the force of the projectiles and the extent of their range.

The momentum of a musket-bullet is vastly inferior to that of a cannon-ball, but the destructive power of musketry is capable of greater concentration than that of artillery. The fire of a line of infantry within the limits of its range is therefore more formidable than that of a battery of the same extent of front.

In defensive combinations, the position of the infantry being fixed, its fire is steady and uninterrupted. In these combinations the power of musketry acts under the conditions most favourable to its effective development.

Jomini, Précis de l'Art de la Guerre, chap. iv. art. 31.

It is available at all times and in every locality, and ought to be regarded as the most certain and universally efficacious means for checking the advance of an enemy and repelling his attack.

Motion being incompatible with the maintenance of a steady fire, musketry cannot be so effectively employed for the purposes of attack as for those of defence.

A cloud of light troops should, however, always accompany those of a column; the fire of the skirmishers will weaken and distract that of the troops defending the position attacked, and will materially contribute to the success of the operation.

If the troops defending a position have suffered no serious loss from the fire of artillery, and can only be assailed in front, the fire of skirmishers will be too feeble to cover effectually the charge of infantry; in such cases, previous to endeavouring to close with the enemy, it may sometimes† be advisable for the advancing infantry to deploy, and, as it advances, occasionally to halt, and endeavour to shake the enemy's line by a fully developed fire of musketry.

Fire of Artillery.

The efficiency of the fire of artillery is in proportion to the number of guns, the fire of which can be concentrated on a given point.

The facility of concentrating guns is therefore an indispensable condition to the effective employment of this species of fire.

In defensive combinations, the artillery of an army must generally be distributed over a great extent of ground, and at critical moments the fire of powerful batteries cannot always be made available at those points where the most vigorous efforts are required to repulse the attack of the enemy. At any particular point, however, the fire of artillery doubles the strength of a position, not merely (as Jomini observes) on

* In 1813 the Russians were beaten at Lutzen and Bautzen by the infantry alone. In a moral point of view these victories were of great importance, but no real material advantage resulted from them. A flying enemy can always rally, unless a blow is rapidly struck in the first moment of disorder.—*Marmont, Esprit des Institutions Militaires*, part ii. chap. i. sect. 2.

†No British troops ought to be in column within canister-shot.—*Editors.*

account of the great distance at which its mischievous effects begin to be felt, and the discouraging influence thereby exerted on troops marching to the attack while they are afar off, but also on account of the havoc which, when they approach within the range of grape, is inflicted on them by the fire of this arm.

In offensive combinations, artillery should be as much as possible concentrated, and the fire of formidable batteries brought to bear on those points where it is desired that the greatest impression should be made.

The fire of infantry, which is the great staple of defence, and which is available against every other species of attack, cannot reach a distant battery.

When, therefore, a position is assailed by artillery, as soon as the guns defending it are silenced, the sole means of opposing active resistance to this species of attack, by troops subjected to the conditions of defence, is destroyed;—either the position must be abandoned, the troops defending it must assume the offensive, or they must passively submit to the havoc caused by the fire of their assailants' batteries.

Whenever powerful batteries are concentrated on a given point in order to overwhelm an enemy by the superiority of their fire, Marmont says that artillery becomes the principal arm of attack; and whether the batteries employed be weak or powerful, it need scarcely be noted that in the attack of fortified posts artillery has always the principal part to perform.

Combination of the Three Arms in the Composition and Organization of an Army.

Précis de l'Art de la Guerre, c. vii. art. 45.

Précis, chap. vii. art. 46.

Jomini says, it may be admitted as a general rule, that one-sixth part of the force of an army in the field should be composed of cavalry. This may be regarded as a maximum. Three pieces of artillery to a thousand men is by the same writer fixed as a maximum, which experience teaches need never be exceeded.* When the infantry and cavalry are courageous and well disciplined, a smaller proportion of artillery will suffice, and in most circumstances good troops will not require more than two guns to a thousand men.—*Vide* Aide-Mémoire, article 'Artillery.'

In this organization of an army, the range of artillery forms the most natural and proper basis for the primary combinations of the three arms.

In these primary combinations the number of guns and the strength of the cavalry are arbitrary,† but the strength of the infantry should be so proportioned to the range of the guns, that the front of the infantry when deployed shall not exceed double the effective range of the guns.

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* The effective strength of the infantry being represented by unity, that of the cavalry should be $\frac{1}{4}$ in a war carried on in a champaign country such as Belgium or Germany; $\frac{1}{8}$ in a country like Spain, and only $\frac{1}{20}$ in a country like Italy.

In 1832 the ratio of the different arms in the French army was—Infantry = 1; Cavalry = $\frac{1}{5\frac{1}{2}}$; Artillery = $\frac{1}{8}$; Sappers and Miners (génie) = $\frac{1}{30}$; Waggon train (équipages) = $\frac{1}{69}$. (*Laisné's Aide-Mémoire*, chap. xii. section 1.

In the estimate for 1862-3, the numbers of the different arms in the British army gave the following ratio—

Infantry (Colonial corps)	= 1
Cavalry (Military Train included)	$= \frac{1}{7\cdot35}$
Artillery	$= \frac{1}{4\cdot9}$
Engineers	$= \frac{1}{22\cdot5}$.

† In the corps d'armée organized by Napoleon at the camp at Boulogne, the cavalry was altogether withdrawn from the divisions. This system, though the Emperor adhered to it in his subsequent campaigns, is not approved of by Marmont.—Vide *Esprit des Institutions Militaires*, part iii. chap i.; see also *Jomini, Précis de l'Art de la Guerre*, chap. vii. art. 43.

By adding to an assemblage of mixed divisions, organized in this way, two reserves, the one composed exclusively of artillery, the other of a mass of cavalry, supported by a few horse batteries, a force will be constituted in which the three arms are combined in a way which is adapted to the exigencies both of defensive and offensive warfare.

In the mixed divisions the three arms mutually support one another, and are so combined as to facilitate the simultaneous development of their destructive powers, which is the mode of development most suitable to the conditions of defence.

By means of the reserves the power of each arm may be developed separately and the different arms made to act successively, which in offensive operations is frequently preferable to their simultaneous employment.

Esprit des Institutions Militaires, part. iii. chap. i.

The proportion in which Marmont recommends that the three arms should be combined in the mixed divisions is, two batteries of foot artillery and seven or eight hundred cavalry to eight or ten thousand infantry.

These proportions are applicable to the three-deep formation of infantry, in which the extent of the front of a division of 10,000 men is about 1950 yards. In the two-deep formation, even 8000 men is too great for the maximum limit of the strength of the infantry of the mixed division. A line of 8000 men formed two deep is upwards of 2300 yards in length, and assuming 1200 yards as the maximum effective range of field artillery, two batteries placed one on each flank of a line 2300 yards in length would afford a very feeble defence to the central parts of the intermediate space.

Two batteries cannot afford an efficient defence to more than 6000 infantry formed two deep : this is at the rate of two guns to a thousand men, but in order to provide for the support of the cavalry and the formation of batteries of reserve, three guns to a thousand men will be required if two batteries and 6000 men be fixed as the proper strength of the artillery and infantry in the composition of the mixed division.*

Esprit des Institutions Militaires, part. iii. chap. i.

The strength of the cavalry reserve, Marmont says, should in no case exceed 6000 men, that number being sufficient to insure success in any enterprise which cavalry can reasonably attempt.

Napoleon, he adds, in his last campaigns organized corps of cavalry composed of three divisions, and numbering at least 12,000 horses : this idea was monstrous, and incapable of any useful application on the field of battle.

The annexed *states* exhibit the application of the above principles to the details of the composition and organization of an army in which 48,000 infantry is assumed as the basis for the formation of the force. (See *States*, Numbers *One* and *Two*, given in the next page.)

According to this view the mixed division is the elementary fraction in which the three arms are first intimately combined.

An army is the unit or perfect whole, and is constituted by the combination of cavalry and artillery reserves, with a suitable number of mixed divisions.

When the force placed under the command of a General exceeds 100,000 men, the cavalry, infantry, and artillery should not be united by the direct combination of their aggregate masses, but a multiple organization should be adopted by dividing the force into two or more bodies, called *corps d'armée*, each containing a proper proportion of cavalry, infantry, and artillery, and so organized as to constitute a distinct and independent army, capable of being employed either separately as an individual unit, or conjunctly as one of those composing the total of a compound body.

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* If the division be unavoidably formed in two lines, the artillery being only required for the defence of the front line, the strength of the infantry may be doubled, that is to say, two batteries will suffice for 12,000.—*Vide* Appendix B.

Note.—As every division of infantry is divided into brigades, the most natural formation will have at least one brigade in reserve, or in a second line.—*Editors.*

STATE NUMBER ONE.

Composition of a Corps d'Armée, 2 Guns to 1000 Men.

Description of Force.	No. of Divisions.	Composition of one Division.		Batteries of 6 Guns.			Total Force.		
		Battalions of 1000 men.	Squadrons of 100 men.	Foot Field Artillery.	Horse Artillery.	Reserves and Position.	Infantry.	Cavalry, $\frac{1}{6}$ of Force.	Guns, 2 to 1000 men.
Mixed Divisions .	6	8	6	2	...	...	48,000	3600	96
Cavalry Reserves .	2	...	30	...	1	...	...	6000	12
Artillery Reserves .	...	...	...	...	2	3	...	...	30
Total . . .	...	...	...	...	...	...	48,000	9600	138

STATE NUMBER TWO.

Composition of a Corps d'Armée, 3 Guns to 1000 Men (nearly).

Description of Force.	No. of Divisions.	Composition of one Division.		Batteries of 6 Guns.			Total Force.		
		Battalions of 1000 men.	Squadrons of 100 men.	Foot Field Artillery.	Horse Artillery.	Reserves and Position.	Infantry.	Cavalry, $\frac{1}{6}$ of Force.	Guns, 3 to 1000 Infantry.
Mixed Divisions .	8	6	4	2	...	...	48,000	3200	144
Cavalry Reserves .	2	...	30	...	1	...	...	6000	12
Artillery Reserves .	...	...	...	...	2	3	...	...	30
Total . . .	...	...	...	...	...	...	48,000	9200	186

Combinations of the Three Arms for the Defence of a Position.

In circumstances where troops act wholly on the defensive (as for instance in the

defence of works), artillery and infantry are the only descriptions of force which can act effectively; in such circumstances, cavalry is less required. An army in the field, however, should always be prepared to repulse the attack of an enemy, not merely by the vigorous use of those means by which an assault is repelled, but also by the development of all its offensive resources, through the medium of a judicious counter-attack.

Précis de l'Art de la Guerre, chap. iv. sect. 30.

Jomini says, "A General who awaits the enemy like an automaton, without having formed any other design than that of fighting bravely, is invariably forced to give way whenever he is properly attacked; not so a General who awaits an attack with the firm resolution to combine great manœuvres against his adversary, so as to regain the moral advantage given by the impulse of attack, and by the certainty of bringing his masses to bear on the most important point,—a certainty which in combinations simply defensive can never be secured.

"He indeed who awaits an attack in a well-chosen position where his movements are free, has the advantage of observing the approach of the enemy. His troops, properly arranged relatively to the ground and aided by batteries so placed as to act with the greatest effect, have it in their power to make their adversaries pay dearly for the ground that separates the two armies; and if the assailants, already shaken by their serious losses, find that they are themselves attacked at the very moment when they imagined victory within their grasp, it is not probable that the advantage will remain on their side, for the moral effect of the offensive being in this way assumed by an adversary believed to be beaten is well calculated to stagger the most audacious."

In accordance with these views, Jomini defines the objects of defence to be—"In the first place, by multiplying obstacles to impede the approach of an enemy, and afterwards by the judicious management of strong reserves to be able at the decisive moment to act vigorously on the offensive at points where a feeble resistance is all that the enemy has been led to expect, and all that he is prepared to contend with."

It is obvious, that in conducting the defence of a position on these principles cavalry will be no less serviceable than the other arms.

In the formation of an army for the purposes of defence, certain general dispositions, such as the arranging of the force in several successive lines, the order of formation of the troops on each alignment, and the relative positions of the cavalry, infantry, and artillery, are in a great measure independent of the nature of the position to be defended. The details of formation, such as the configuration of the lines of defence (whether straight, convex, concave, or irregular), the distance between the different lines, and the proportion of the total force which should be allotted to each, cannot be absolutely determined. These details depend principally on local circumstances, and require to be so arranged that the lines of formation may correspond with the lines of defence determined by the accidents of the ground to be occupied, and that a greater force may be provided for the defence of those points where no natural obstacles exist, than for those where the ground is strong and the position difficult of access.*

The following outline of the method of arranging an army for the defence of a fixed position only embraces those points which are common to all defensive arrangements. It will be found consistent with the general practice of modern commanders and suitable to the conditions imposed on the development of the power of the three arms by the objects of Defensive Warfare.

Vide Appendix B.

The infantry is drawn up in four alignments.

* See article 'Position.'

The troops on the first alignment are formed at open or skirmishing order; on the second they are in close order; on the third, formed in columns of battalions at deploying distance, supported by strong divisions, each consisting of one or more brigades formed in mass of battalion columns.

Précis de l'Art de la Guerre, chap. vii. art. 43.

Esprit des Institutions Militaires, part iii. chap. viii.

The skirmishers being always detached from the line in their rear are not reckoned as a distinct corps; although therefore the development of the infantry is fourfold, yet its division is only threefold. The three fractions are respectively distinguished as the first and second lines and the reserve.

The cavalry is drawn up in rear or on the flank of the infantry.

The squadrons of the mixed divisions are distributed along the rear of the second line of infantry, immediately behind the divisions to which they are attached, out of cannon-shot.

The cavalry reserves may be formed in échellon on the flanks of the army, or they may be posted in rear of the second line of infantry, so as to support some particular part of the position where the ground is favourable for the action of cavalry.

The artillery attached to the mixed divisions, reinforced by a portion of the heavy batteries of the reserve, should be so placed as to flank the deployed line of infantry in the same way as the bastions of a fortification flank the intermediate curtains.*

By this arrangement a cross fire of artillery will co-operate with a direct fire of musketry to defend every point of the position, and to oppose the approach of an attacking force. The horse batteries,† and the remainder of the heavy batteries of the artillery reserve, are formed in columns on the flank, or in the rear of the infantry reserves.

When an army thus arrayed for defence is attacked by an enemy, the first resistance is offered by the skirmishers detached from the first line. Extended in front of the position, supported by squadrons of light cavalry, and, where possible, protected by natural obstacles, these troops by a fire of musketry vigorously oppose the cloud of light troops thrown forward by the enemy to cover the deployment of his columns. As soon as the enemy approaches within cannon-shot, the artillery by which the position is defended opens its fire, first co-operating with the effects of the light troops in retarding the establishment of the hostile batteries, and afterwards endeavouring to silence their fire and dismount their guns.

When the light troops of the defenders have been driven in, should the enemy push forward masses of infantry, the fire of the infantry and guns occupying that part of the position which is assailed are concentrated on these troops.‡

If the advancing masses are not checked by this concentrated fire, a bold charge of the opposing line often strikes them with dismay, arrests their progress, and drives them back in confusion.

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* Artillery in an order of battle is placed at the salients, and at those points where the position is weakest, either from those points being easy of access, or from the smallness of the force defending them. It ought to be placed so as to enfilade the different roads, communications, ravines, and outlets of valleys by which the enemy can present themselves; above all, it is necessary that it should be able to play upon the foot of the heights upon which it is established: eight feet in one hundred is the maximum of inclination of those slopes which offer an advantageous position for a battery.—*Laisné's Aide-Mémoire*, chap. xii. sect. 1.

† At least one-half of the horse artillery should be kept in mass with the reserve, in order to be rapidly moved to any point where it may be wanted.—*Jomini, Précis de l'Art de la Guerre*, vol. ii. p. 274; see also *l'Esprit des Institutions Militaires*, part iii. chap. 1.

‡ It ought never to be forgotten, that in action the principal office of every species of artillery is to crush the troops of the enemy, and not to reply to his batteries; nevertheless, it is well not to leave the enemy's batteries entirely unmolested: a third part of the disposable guns may, therefore, be employed to annoy the enemy's artillery, but at least two-thirds must be constantly employed against the infantry and cavalry.

If, instead of infantry, masses of cavalry be employed to force a position, the infantry defending it form battalion squares, the ammunition waggons and limbers are withdrawn, and the guns distributed in half-batteries or sections between the squares, within which at the moment of attack the gunners take refuge.

If the enemy fail in breaking the squares, the cavalry in rear of the division attacked instantly charges and gradually succeeds in driving back the assailing squadrons. The attacks of the French cavalry were in this way repeatedly repulsed by the Austrians at Aspern (or Essling), and by the British at Waterloo.

The first efforts of an attacking force are invariably resisted by the skirmishers and first line of the force attacked, in the manner above described.

Should the enemy be successful in overcoming the resistance of the first line, the same uniformity of practice does not exist with regard to the method of employing the second line and reserves in resisting his further progress. Sometimes, after the repulse of the first line we find the second line deploying, assuming a new line of defence, and defending it precisely on the same principles as the first line was defended : meanwhile the reserves manœuvre so as to be ready in case of a second disaster to deploy in a third position, and to endeavour to maintain it by a third repetition of the original system of defence. Sometimes, on the other hand, as soon as the enemy's plan of attack is fully developed, or at all events as soon as it becomes evident that the first line will not be able to maintain its ground, we find the second line, in co-operation with the cavalry reserves, assuming the offensive, and endeavouring by the combination of skilful manœuvres with a bold counter-attack to drive back and overthrow any portion of the hostile force which may either have succeeded in penetrating the first line, or which may have compromised itself in making the attempt.

The advantages of the latter system have already been indicated, and some further observations will be found in the next section, tending to show, that if the second line simply attempt to maintain its position, it runs a great risk of being involved in the defeat of the first, whereas, if it boldly attack the enemy before his troops have time to recover from the disorder occasioned by their struggle with the first line, it is highly probable that the effort will be successful, and will result in the complete repulse of the enemy's force.

Nevertheless, it must be admitted that there are cases where the opposite system may be adopted with advantage, and that good troops arrayed in a series of defensive lines may maintain themselves in a strong country against very superior numbers, whereas by attempting to operate offensively they would in such circumstances incur a great risk of involving themselves in a contest, which, in case of the issue being unfavourable, would result in their total ruin.

Rear-guards, when attacked, are usually obliged to conduct their defence on this system, to avoid the risk of more than one line being forced by a single effort : the distance between the lines should be considerable ; the line in the rear should be supported by artillery, and the defence of the first line should be abandoned in time to prevent the troops being broken and overwhelmed by contact with the superior masses of the enemy.

Combinations of the Three Arms for the Attack of a Position.

The following observations respecting combinations for attack are extracted from the 4th chapter of Jomini's 'Précis de l'Art de la Guerre :'

"The essential object of an offensive battle being to dislodge the enemy from his position, and above all to throw him into the utmost possible disorder, the employment of physical force must usually be relied on as the most efficacious means for arriving at these results. Nevertheless, it sometimes happens that the hazard of

trusting solely to the employment of force is so great, that success may be more easily obtained by means of manœuvres calculated to outflank the wing of the enemy's army which is nearest his line of retreat."

Of these two means of attack, being the employment of physical force, and the employment of outflanking manœuvres,* the former is that which is the intermediate object of the present investigation. Concerning it, Jomini delivers the following maxims :—

"It is difficult to determine, in an absolute manner, which method is the best that can be employed to force an enemy's line to quit its position. Any order of battle or of formation which should succeed in combining the advantages of fire with those of the impulse of attack, and of the moral effect it produces, would be a perfect order. Lines and columns, skilfully mingled, and acting alternately as circumstances and opportunities vary, will always be a good system."

In the following passage, Jomini first describes the method of combining artillery, cavalry, and infantry, in attacking the first line of an enemy ; he then discusses the value of success in the first shock, with reference to the manner in which such success affects the ability of each of the contending armies to renew the struggle, and to the influence which it exercises on the final event of the engagement.

"The different means that must be used to carry a position, that is to say, to break the enemy's line, and to compel it to retreat, are, first, to shake the line by a superior fire of artillery, then to produce in it a certain degree of disorder by a well-timed charge of cavalry, and finally to direct on the line, thus shaken and disordered, masses of infantry, preceded by skirmishers, and flanked by a few squadrons of cavalry : even, however, taking it for granted that a combined attack of this sort will be successful against the enemy's first line, there still remains to be beaten the second line, and after it, the reserve. At this point the difficulties of the attack would, therefore, have only become more serious than before, were it not that the moral effect of the defeat of the first line frequently leads to the retreat of the second, and causes the General of the army attacked completely to lose his presence of mind.

"Yet it is evident, that in spite of their success, the troops of the first line of the assailants must also be somewhat disorganized, and that it will frequently be very difficult to replace them by those of the second line ; not merely because the troops of the second line do not always follow the movements of the operating masses after they arrive within the range of musketry, but more especially because it is always hazardous to replace one divison by another in the midst of a battle, and at the instant when the enemy should make the most powerful efforts to resist the attack.

"There is, then, every reason to believe, that if the General and the troops of the force attacked did their duty, retained their presence of mind, and were not menaced on their flanks and line of retreat, the advantage of the second shock would be almost always on their side. But, in order to secure this result, it is absolutely essential to recognise by a rapid and decisive glance the precise instant when it becomes expedient to precipitate the second line and cavalry reserves upon the victorious battalions of the enemy. Even the loss of a few minutes may become irreparable, for the risk is incurred of the second line being involved in the defeat of the first, and hurried away with it in its flight.

"The following truth respecting the conduct of an attack results from the preceding observations :—

"The most difficult, but at the same time the most certain, means of success is, to support efficiently the line first engaged by the troops of the second line, and these

* The battle of Vittoria is a good example.—*Editors.*

by the reserve, at the same time carefully calculating the employment of the cavalry and artillery reserves, so that the decisive struggle with the second line of the enemy may be aided by their co-operation.

"This is the greatest of all the problems connected with the tactics of battles.

"It is in the resolution of this important problem that theory becomes uncertain and difficult in its application, because it here finds itself unequal to the emergency, and must always remain inferior to the spontaneous suggestions of a genius naturally warlike, or the instincts of an eye habituated by the practice of command to survey the turmoil of battle with a calm, intrepid, penetrating glance. To devise means at the decisive crisis of an engagement for the employment of a force composed of all the arms combined in the greatest possible numbers (exclusive of a very small reserve of each arm, which should always be kept on hand), is then the problem to the resolution of which every skilful General will apply himself, and according to the conditions of which he will regulate the movements and combinations of the forces under his command.

"Most commonly the decisive crisis of an engagement is the moment when the first line of one of the contending armies is broken, and when the utmost efforts of both are exerted—on the one side, in order to complete the victory; on the other, in order to snatch it from the enemy.

"It is unnecessary to say that a simultaneous attack on the enemy's flank will have a most powerful influence in rendering the decisive blow more certain and effectual."

The following sketch of the formation of an army for an attack, and of the manner of conducting it, is, with some alterations and abridgments, translated from Giustiniani's 'Essai sur la Tactique des trois Armes.'

When an army approaches the position which it is intended to assail, and, as the ground opens, the distance between the columns of route is diminished, and the breadth of their fronts is gradually enlarged.

When the advanced guards begin to feel the enemy's piquets, an order of manœuvre is assumed, by subdividing the columns of route, first into columns of divisions, and then into columns of brigades, between the heads of which, intervals sufficient for deployment are preserved.

Within three-quarters of a mile or a mile of the enemy the formation of attack is developed.* Bands of skirmishers, supported by the cavalry and artillery attached to the divisions, are thrown out. Covered by the fire of the skirmishers and guns, the masses of columns halt and deploy into line of contiguous columns, which are formed either simultaneously or successively on a double alignment; the reserve takes its station 1000 or 1200 yards in rear of the second line.

Vide Appendix B.

When the enemy's skirmishers have been driven back to a sufficient distance, the batteries advance and are established as close as possible to the hostile line. The infantry follows, and the cavalry attached to the divisions retires and takes post in rear.

The enemy's position is now vigorously cannonaded in its whole extent: such battalions of the front line as are much exposed to the projectiles of the enemy deploy, and wherever it is practicable to get within range, a fire of musketry is opened on the hostile line.

These general demonstrations, when judiciously conducted, by pressing the enemy on several different points, are calculated to distract his attention, and

* A column of 30,000 infantry marching on a single road, with full distance between its sections, occupies about 8700 yards. From two hours to two hours and forty minutes will be required to enable this force to deploy on a double alignment, one-half of the force to the right, and the other to the left of the road.

to give a wrong direction to the movements of his reserves. Meanwhile, preparations are made for a decisive effort : for this purpose a favourable point is selected on which the fire of the artillery reserve is suddenly concentrated; under cover of this fire, arrangements are made to precipitate an overwhelming force on the troops by which it is defended.

Précis de l'Art de la Guerre, chap. vii. art. 46.

This force should consist both of cavalry and infantry.

The order for it to advance should not be given until the enemy's line shews symptoms of being shaken by the cannonade.

At length it is perceived that its fire begins to slacken, or perhaps some indications are observed of an intention to effect a change of position.

This is the critical moment to command a charge.

According to circumstances, either the cavalry or infantry may lead. When the cavalry leads, the charge is executed in several successive lines.

If the troops attacked have not time to form squares, or if the squares give way, not only will the position be carried by this method of attack, but the infantry defending it will be ridden down and destroyed.

Columns of infantry formed at deploying distance should follow the cavalry.

According to circumstances, these columns may either continue their advance, deploy on the position they have won, or, if to save his broken infantry, the enemy bring forward his reserves of cavalry, they must form square so as to enable the squadrons dispersed in pursuit to be collected and re-formed in their rear.

Should it be determined to employ infantry to carry a position, a line of battalion columns, connected by skirmishers filling the intervals, is the formation which seems to combine the greatest number of advantages.

Vide Appendix A.

The cavalry deployed on the flank of the line of columns is ready to repulse any attack of the enemy's cavalry.

If on the near approach of the attacking columns the troops defending the position give way, the cavalry must endeavour to cut off their retreat, and effect their destruction by a charge. If this cannot be effected, the infantry columns will halt, the guns and second line will move forward to their support,* and preparations will be made either for maintaining the ground that has been gained, or for a further advance, as circumstances may require.

The general views contained in the following extract from Laisné's 'Aide-Mémoire Portatif' will serve to connect together the preceding sections, and to conclude the subject of Attack and Defence.

"All the combinations for the conduct of an army in a battle may be reduced to three systems.

"The first system, which is purely defensive, consists in awaiting the attack of an enemy in a strong position, without any other design than that of maintaining possession of the ground.

"The second, on the contrary, which is entirely offensive, consists in marching to attack the enemy wherever an enemy can be found.

"The third is a middle term between the two others; it consists in choosing an advantageous field of battle, awaiting the attack of the enemy, and seizing during the combat a favourable opportunity to assume the initiative.

"It is only the two last systems which can be advantageously adopted.

"Regarding the application of these two, the following rules may be laid down as generally, though not absolutely and invariably, true :—

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* In conducting an attack, care must be taken not to compromise the foot artillery. It may be placed so as to afford efficient support to the troops without following too closely the attacking columns.—*Jomini, Précis de l'Art de la Guerre*, chap. vii. art. 46.

"1. With troops accustomed to war and in an open country, it is always most advantageous to assume the initiative, and to act on a system purely offensive.

"2. In a difficult country, with well-disciplined and obedient troops, it is perhaps most advantageous to await the attack of the enemy in a good position previously selected, and not to assume the offensive until the enemy's troops have by their first efforts, to a certain extent, exhausted their strength.

"3. The strategical position of the two parties may render it indispensable for one of them to attack by main force the position of his adversary, without any reference to local considerations; for example, this may be necessary, to prevent the junction of two corps, to fall upon a detached portion of an army, or to overwhelm an isolated corps on the further bank of a river."

Combinations of the Three Arms in the Movements of Armies.

The general principle for the regulation of these combinations is laid down in Giustiniani's Ninth General Rule—

"In manœuvres and march manœuvres, in order to facilitate the simultaneous movements of the three arms, it is necessary carefully to avoid obliging any one of them to adopt the rate of march peculiar to the others."

In route-marching on a high road the infantry march at the head of the column, next come the artillery and baggage, and the cavalry bring up the rear; the hours of commencing the march are so regulated that considerable intervals may separate each species of force.

When manœuvring in presence of an enemy, the three arms should not be mingled in the same column, but each arm should move on the point where it is to form in a separate column; the cavalry generally being in the flanks, the infantry in the centre, and the artillery between the cavalry and infantry, and also, when the infantry columns are numerous, in the intervals between the columns.

When cavalry manœuvres in front of infantry, the infantry ought to be formed in battalion columns at deploying distance. If the cavalry be beaten, the broken squadrons retire through the intervals of the columns which form square, and oppose by their fire the pursuit of the enemy's cavalry.

When, on the other hand, infantry manœuvres in front of cavalry, the cavalry ought to deploy in their rear, ready to cover by a charge the retreat of the infantry.

In the movements of lines, whether executed by the fractions moving alternately in chequer or successively in échelon, the artillery is so distributed as to fire by alternate divisions. The cavalry is kept in readiness to debouch either by the flanks of the line or by the intervals between the fractions of which its formation is composed.

The retreat of a line retiring by alternate or successive fractions is greatly facilitated by a sudden and judicious display of cavalry.

Giustiniani. "In all offensive movements, and especially in the passage of lines to the front, the artillery supported by cavalry precedes the infantry, and covers the movement by the formation of batteries in a lateral and advanced position, so as to bring a cross fire to bear on the enemy.

"If, on the other hand, it is required to effect the passage of lines in retreat, a portion of the artillery is placed in a good position in rear,—the remainder continues its fire until the first line of troops begins to retreat, and then follows the movement. The cavalry is kept in readiness to check the pursuit by a charge."

In changing the direction of a line, a strong battery is first established on the pivot flank.

When the change of direction is to the front, the cavalry takes post on the outer flank, and follows the movement. When the change is to the rear, the cavalry masks and covers the movement by deploying on the old alignment.

CONCLUSION.

A sketch has now been given of the principles which ought to regulate the combinations of the three arms. It cannot be doubted that the proper application of these principles exercises a very important influence on the result of battles.

But however highly this influence may be estimated, it must be admitted that there is much truth and force in the following remark of Jomini :—

"Victory does not always depend on the superiority of the arm employed, but equally on a thousand other circumstances. The courage of the soldiers, the presence of mind of the general, a well-timed manœuvre, cold, heat, rain, and even mud, have all contributed to reverses and successes. Let us then, conclude, as a general maxim, that a brave man, whether on foot or on horseback, should always be able to get the better of a coward."

APPENDIX A.

Formations for Attack.

1. *Cavalry.*—The formations which are most suitable for the execution of charges against cavalry, infantry, and artillery, are explained in the article 'Manœuvres of Cavalry.'

2. *Infantry.*—In arranging a mass of infantry for the attack of a position, one or other of these four systems of formation must necessarily be adopted :

1. It may be formed in a line consisting of two or three ranks.
2. In a line of battalion columns.
3. In a mass of columns.
4. In a line partly deployed and partly in column.

Concerning the first of these three systems, Jomini writes :—"Is it possible to conduct the march of an immense line, consisting of battalions deployed and firing as they march ? I believe that it is not. To set in motion, with the view of carrying a well-defended position, twenty or thirty battalions formed in line, and keeping up a fire either by files or by divisions, is to resolve to arrive at the position in disorder, like a flock of sheep, or rather it is to resolve not to arrive there at all."

Concerning the third system, he says, "This is certainly the formation which is least suitable for leading troops against an enemy. We have seen in the last wars divisions of twelve battalions deployed and heaped on one another, forming a mass of thirty-six crowded ranks. Such masses are exposed to the ravages of artillery,—they impede freedom of movement and the communication of a forward impulse, without contributing anything to stability and strength. The adoption of this formation was one of the causes of the failure of the French at Waterloo; and if Macdonald's column succeeded better at Wagram, it paid dearly for its success; nor is it probable that this column would have extricated itself victoriously from the situation in which at one time it was placed, had it not been for the favourable issue of the attack of Davoust and Oudinot on the left of the Archduke."

The second and fourth systems are both spoken of with approbation by Jomini. He says, "Of all the experiments which I have seen to ascertain the best formation for leading infantry against an enemy, that which seemed to me to succeed the best was the march of twenty-four battalions in two lines of battalion columns formed at deploying distance. The first line advanced at the quick step, and, on arriving within twice the range of musketry, deployed in double time. The light companies of each battalion extended to cover the formation; when it was completed, the other companies commenced file-firing. The second line followed the first, and the columns composing it, passing through the intervals left by the light companies, threw themselves on the enemy. It is true that this was not done in presence of a real enemy,

but it seemed to me impossible that anything could have resisted the double effect of the fire of the line and the impulse of the columns."

The columns considered by Jomini most eligible for the purposes of attack are columns of grand divisions formed on the two centre companies of battalions, consisting of eight companies, each of three ranks; this gives a depth of twelve ranks to the column: ten ranks will be the depth of a column similarly formed by a battalion of ten companies, each consisting of a double rank.

APPENDIX B.

On the Distribution of Troops formed on a double Alignment.

1. *Cavalry.*—All tacticians agree in thinking that when cavalry is formed on several alignments, the general officer who commands any portion of the front line must also command the corresponding portions of the lines in its rear.

Jomini says, "In deploying a division of two brigades it would be wrong to place one brigade in the front line and the other in its rear; the proper arrangement would be to place one regiment of each brigade in the front line, and the other regiment in the second: thus each unit of the line would have its own reserve immediately in its rear, an advantage which is by no means to be undervalued, for in cavalry charges events succeed one another so rapidly that it is impossible for a general officer to be master of two regiments deployed."

2. *Infantry.*—It is a disputed point whether it is better to deploy a division of infantry on a single alignment, or to deploy one-half on the first line and one-half immediately in its rear on the second. The advantages of deploying each division on a single alignment are—

(1.) Changes may be made in the disposition of one of the lines, and portions of it may be removed from one flank to the other without reference to the disposition of the other line, and without destroying the unity of a division by separating its halves.

(2.) In effecting the deployment of a column composed of several divisions, the first line will be formed more quickly if all the battalions composing the divisions at the head of the column deploy on the same alignment, than if the first and second lines be formed simultaneously by the divisions successively deploying one-half on the first and one-half on the second alignment.

The advantages of deploying a division on a double alignment, and placing one-half in rear of the other, are—

(1.) The troops in front and those in rear being commanded by the same individual, those in front will be more promptly and effectively supported than if the officer commanding the first line had no command over the troops in his rear. This advantage is considered by Marmont as conclusive.

(2.) The whole of the divisional artillery may be placed in battery in the front line without any part of it being separated from the division to which it is attached.

Giustiniani, who discusses this question very fully, thus sums up the argument:—

Both methods may be good, and on any particular occasion the circumstances of the case must determine which is to be preferred. For example, in an open level country, where a contiguous line of battle must be formed, the whole of a division should be deployed on a single line; in a hilly, woody, broken country, on the contrary, where the line of battle must be formed of detached parts, it may frequently be preferable to form a division in a double line, for it must be admitted that it is impossible to exercise an effective superintendence over a great extent of front broken by the accidents of ground, such as ravines, ditches, woods, &c."

A. Robertson.

TAMBOUR.*—A *tambour*, as its name imports, especially relates to the protection of gateways or other means of access to works; and although this description of defensive work is more generally considered in the character of a temporary expedient (and is included by French writers as a 'réduit en charpente') than as forming a part of permanent construction, it is so applicable in retrenching the places of arms of a covert-way, for covering the pas de souris, and descent into the ditch of a fortress, and in detached lunettes, as well as in covering the entrance of small forts, when a tenaille or ravelin could not be adopted, that there appears no reason why on such occasions the line of cover should not be a brick wall instead of a stockade.

The tambour figure has sometimes been a segment affording a converging fire; but it is much better to give it an angular form, cutting off portions of the angles about six feet on each side, if it be desired to obtain direct fire on their capitals. The best figure for a tambour is that of two faces and flanks, returned also to the gorge if necessary. Generally, the faces should be at least 30 feet long, and the flanks 20 to 25 feet.

The exterior should, if possible, be flanked from some part of the principal or a collateral work; and with a pointed ditch in front; or surrounded by a row of short palisades, to check an enemy under the fire from the tambour.

Tambours en charpente are constructed of squared or sided timbers placed close to each other, planted vertically about 3 or 4 feet in the ground, and rising about 8 feet above it. The scantling should be 7 inches thick, if of oak or hardwood, and about 10 inches thick, if of fir. The stockade thus formed is pierced by two rows or tiers of crenels, or common narrow-mouthed loopholes, the height of which will depend upon the desired line of fire; but, as a tambour is of low relief or profile, not intended for command, the lower row of loopholes may be about 3 feet, and the upper tier 4 feet 4 inches above ground, with intervals of $3\frac{1}{2}$ or 4 feet,—the upper crenel being over the centre of the lower interval.

It is desirable that the interior line of tambour should be covered by a blindage sufficiently strong to resist the effect of grenades, thus forming a gallery about 6 feet wide, the roof being supported on a row of inner columns. This or some less substantial shed-roof is especially desirable for all stockades or advanced musketry retrenchments in countries subject to heavy falls of snow, so that the banquette may be always in a state to be manned by infantry.

Although tambours are usually made of timber, it may be advantageous in some cases to adopt more permanent construction for this description of small defensive post; and then a crenelled wall of brickwork, with a groined corridor, having a ridge or batardeau-like top, will be preferable to a temporary construction.

A permanent tambour, to serve also as a guard-house to a re-entering place of arms, was constructed in the covert-way of Quebec citadel, on the suggestion of the Inspector-General of Fortifications in 1842; and tambours of temporary construction were recommended by the Duke of Wellington, in front of the gateways of barracks in Ireland, in 1843.—E. F.

TELEGRAPH, ELECTRIC.—See 'VOLTAIC ELECTRICITY.'

TELEGRAPH, FIELD.†—"The telegraphs were composed of a mast and

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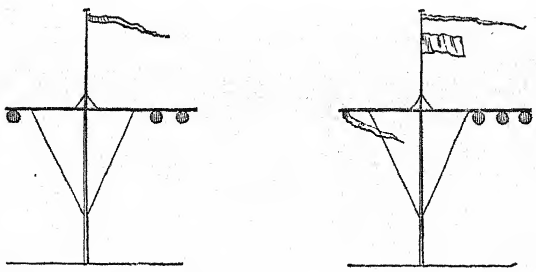
* By the late Major-General Fanshawe, R.E.

† From 'Memoranda relative to the Lines thrown up to cover Lisbon in 1810.' By Major-General Sir John Jones, Bart., K.C.B. & R.E.

yard, from which latter balls* were suspended : the vocabulary used was that of the Navy, many sentences and short expressions peculiar to the Land Service being added. These telegraphs readily communicated with each other at the distance of seven or eight miles; but in consequence of the ranges of hills interrupting the view, it required five principal stations to communicate along the front line."—(*See* article 'Fortification, Field,' vol. ii. p. 29.)

The telegraphs were worked by a party of seamen.

Fig. 1. Fig. 2.



TELEGRAPH, UNIVERSAL.†

General Description of the Universal Telegraph.

For the day signals, the telegraph consists of an upright post of moderate height, of two moveable arms fixed on the same pivot near the top of it, and of a mark, called the indicator, on one side of it. (See Plate I. fig. 1.)

Each arm can exhibit the seven positions 1, 2, 3, 4, 5, 6, and 7, exclusive of its quiescent position, called 'the stop,' in which it points vertically downwards, and is obscured by the post. Fig. 1 also represents the telegraph exhibiting the sign 17, the other positions of which the arms are capable being dotted. The indicator merely serves to distinguish the low numbers, 1, 2, and 3, from the high numbers, 7, 6, and 5, so that this telegraph is not, like most others that have been proposed, liable to ambiguity or error when viewed from different points in contrary directions.‡

The use of the indicator will appear more evident, on considering the resemblance between the small Roman letters b and d, or p and q, which, if viewed in contrary directions, like telegraphic signs, could never be distinguished one from the other, without some additional mark.

Fig. 2, Plate I., represents the telegraph fitted up for making nocturnal signals. One lantern, called the central light, is fixed to the same pivot upon which the arms move. Two other lanterns are attached to the extremities of the arms. A fourth lantern, used as an indicator, is fixed on the same horizontal level with the

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* Balls constructed of wicker or basket-work are frequently used, and at a little distance appear solid; hence they may be made by Sappers, in the manner of gabions or hurdles. See figs 1 and 2.—*Editors.*

† By the late Lieut.-General Sir Charles Pasley, K.C.B., F.R.S., & R.E.

‡ The idea of the indicator, which was not a part of my original plan, but without which I am now of opinion that no telegraph is perfect, suggested itself in consequence of a remark made by my friend Captain John Tailour, of the Royal Navy, who informed me that he had experienced the greatest inconvenience in using Sir Home Popham's ship semaphores, from the signal-men confounding the positions of the arms when seen in reverse.=C. P.

central light, at a distance from it equal to twice the length of one arm, and in the same plane nearly in which the arms revolve. Hence the whole apparatus consists of two fixed and of two moveable lights, four in all.

The number of telegraphic signs, combinations, or changes which this telegraph is capable of exhibiting are only twenty-eight, but these are amply sufficient for every purpose of telegraphic communication, whether by the alphabetical method, or in reference to a Telegraphic Dictionary of words and sentences. These signs are represented in Plate II. in a double column, shewing the appearance of the same combinations, both by day and night.

In some few of the nocturnal signs, it will be observed that one of the lights is marked black. This only happens when one of the moveable lanterns is supposed to be in its quiescent position, hanging vertically down below the centre light. In this case, as the lantern may be exhibited on either side of the post, it may sometimes be seen and sometimes not by the distant observer.* At first I proposed to interpose a couple of screens, one on each side of the post, to hide the lanterns altogether, when in this position. Afterwards that idea was abandoned, it having been found in practice that it made no difference, in regard to the clearness of the signs alluded to, whether the moveable lanterns were seen or obscured when in the position denoted by the black circles.

The indicator, both by day and night, being merely a mark and nothing more, which, when once seen, requires no further attention to be paid to it,—and the central light by night and the post by day being also merely guides to the eye,—the signs of this telegraph are, in reality, composed of the combinations of two moveable bodies only by day and of two moveable lights only by night, being the smallest number of parts with which an efficient telegraph can possibly be formed : and in this diminution of the number of combinable parts, as well as in the unity of plan, consists the superior simplicity of this telegraph, as compared with other efficient telegraphs that have been proposed.

The Mechanical Construction of the Universal Telegraph. (Plate I. figs. 3 and 4.)

The arms and the indicator for the day signals are made of wood, framed and panelled, for the sake of lightness.† The indicator plays in a mortise cut in the upper part of the post, and is let down into its horizontal and raised into its vertical position by means of a small rope and a small pulley. The arms must be fixed externally, one on each side of the post, and must be exactly counterpoised by means of light frames of open ironwork, which become invisible by day at a little distance,

* A great difficulty is hitherto said to have attended the night signals in the Royal Navy, in consequence of the embarrassing circumstances of one or more of the lights exhibited being liable to be extinguished by eddy winds thrown off from the leaches of the sails in stormy weather.

Admitting that this difficulty should prove insuperable, upon which point I shall not presume to decide, a question arises as to the best and simplest mode of guarding against mistakes arising from this cause, which in *general signals*, relating to manœuvres, might lead to unpleasant, if not to pernicious, consequences. An effectual remedy for this evil (in fact I see no other) is to make a rule of never exhibiting any sign with fewer than four lights. This being understood, if the signal-men who receive a message should at any time observe fewer lights than four, they will know that an accident has occurred in consequence of the wind, and they will therefore take no notice of the apparent sign displayed until the complete number of four lights again appears.

This arrangement can be adopted in regard to the nocturnal telegraph by exhibiting the quiescent light always in front of the post when two ships only are telegraphing to each other, but a little to one side of it in telegraphing both to the front and the rear; also by disusing the sign called 'the stop,' in which two or three lights only appear, and exhibiting one of the *preparatives* always in lieu of it.

† In a very hot climate plates of light copper may be used for the panels.

and which, even when viewed closely, do not impair the clearness of the telegraphic signs. This precaution is absolutely necessary, otherwise the arms will not remain in any given position without being held by the hand or stopped by some mechanical contrivance, which would be a very great inconvenience in the practice of signal-making.

Motion may be communicated to the telegraphic arms by means of an endless chain passing round and acting upon a couple of pulleys, one of which is fixed to the arm itself, and turns upon the same pivot, whilst the other moves upon a pivot fixed to the lower part of the post. The chain consists alternately of single and double plates of an oblong form, and riveted together at the ends on the principle of a watch-chain. The two pulleys at top and bottom being finished with great care, perfectly equal, and having projecting teeth or studs fixed in a groove in each to engage the double or open parts of the chain, the telegraphic arm above will always follow to a hair's breadth the movements of an index or lever below, attached to the lower pulley, which has a dial-plate opposite to it, marked on the post, for the guidance of the operative signal-man.*

In the field, or on board ship, a leathern strap or a rope may be substituted in lieu of the chain, for the sake of economy; but as these expedients are incapable of the same accuracy as the former, the signal-men, in working by them, must not trust to the indices, but must regulate the positions of the arms chiefly by the eye. The surface of the pulleys, when intended for a strap, must be moderately convex, those for the rope moderately concave, and both should be broader than when a chain is to be used. The leathern strap requires an extra pulley of a smaller size for pressing in one side and tightening it when the telegraph is to be used. This pulley is fixed to a small lever attached to the middle of the post, and is thrown into action by a string.

When a rope is used, three turns of it are taken round each pulley, hauling it taut at the same time, after which the two ends, being previously prepared with thimbles, or eye-splices, are brought towards each other and made fast by a lanyard, or smaller rope, passing through the eyes.†

When the strap or rope is used, the lower pulley, instead of having one short lever only, serving as an index, may have four such levers, so as to resemble a small windlass.

At the end of each arm two light pieces of iron meet in an angle of 45 degrees, forming an open triangle, to the vertex of which the moveable lantern (L) is attached by means of a pin. A cylindrical weight (W) must be fixed at the same time to the end of the iron counterpoise to restore the proper equilibrium of the arms, which is of course deranged by the addition of the lantern (see figs. 3 and 4).‡ As the lanterns

* The chain is first passed loosely round both pulleys, after which the pivot of the lower pulley is acted upon by a couple of screws to force it down a small vertical groove in the post, by which means the chain is tightened and rendered fit for use. I had a telegraph constructed in this manner at Chatham in 1817, by Mr. Robert Howe, Clerk of Works in the Royal Engineer Department, of which a model was sent to the Secretary of the Admiralty in 1818.

The above method of moving telegraphic arms by means of the lever and chain is much more expeditious, and also simpler in point of workmanship, than the winch and wheel-work and endless screw-rods originally adopted for the same purpose in the Admiralty semaphores. In fact, in moving the arm from one position to another the chain will work at least four times quicker than the winch.

† This contrivance was used for working the Admiralty ship semaphores. Its great simplicity recommends it for the sea service, although in other respects not the most convenient method.

‡ By this arrangement of the ironwork which supports the lanterns, they always hang clear of it in the regular positions, and the iron counterpoises are made so much shorter than

and weights, and, in short, every addition necessary for exhibiting the nocturnal signals, are fixed at dusk, and removed by daylight, it becomes necessary, at permanent stations, that the roof of the signal-house over which the telegraph stands should be formed with a small flat terrace, accessible by means of a ladder or staircase.

In the intermediate stations of a permanent telegraphic line on shore two lanterns are required to do the duty of the centre light, one on each side of the telegraphic post, because one lantern can, of course, be seen in one direction only, owing to the intervention of the post. These two, as well as the two moveable lanterns, are fixed externally at a sufficient distance from the plane of the arms to prevent them from striking, as in fig. 4, in which C C are the central lanterns, L L the moveable lanterns, and W W the weights added to counterpoise them.

The indicator light (I) may either be fixed to a separate post, as represented in fig. 2, or it may be attached to a rod (*r*), strengthened by a brace (*b*), and guy-ropes (*g g*), as in fig. 3, which is an elevation of the Universal Telegraph, fitted up for night signals, on a scale larger than that of the former explanatory figures. The apparatus now alluded to, having only one lantern to support, may be made extremely light. The end of the rod drops into a small open mortise at the head of the post, and has a semicircular groove on its lower surface, which is engaged by a horizontal bolt driven through the sides of the post. A small rope fixed to the end of the rod, but omitted in fig. 3 for the sake of clearness, is made fast to a cleat upon the post below, to prevent the rod from moving. The foot of the brace is secured to the post by a plate and stud.

This apparatus, which entirely depends upon the telegraphic post, and turns with it, may be fixed or disengaged in a moment, and is peculiarly adapted for ships and for field service, in which the length of the telegraphic arm does not exceed from 5 to 6 feet. But at permanent stations on shore, where larger telegraphs would probably be used, the apparatus for supporting the indicator lamp should be a permanent fixture, to save the trouble of continually shipping and unshipping it. At such stations, if the signals were required to be made in various lines or directions, the pole for supporting the indicator lamp should be fixed to the post at bottom, so as to stand out from it obliquely, like a ship's bowsprit, with lifts or ropes to support it, leading to the top of the post, and a couple of guys to secure it from lateral motion. Hence one oblique spar only would be used, instead of the two pieces (namely, the rod and brace) before described. But as there may be many stations in a telegraphic establishment on shore in which the signals require to be exhibited in one invariable line only, at all such stations the indicator lantern should be fixed to its own separate post, which may either be placed vertically (as in fig. 2), or obliquely, as may be considered most expedient.*

Lamps for burning oil were subsequently brought to such perfection that a light of sufficient intensity for any distance suitable for telegraphic purposes might easily be obtained. In regard to form, when night telegraphs are adopted on shore, square lamps, having the two glass sides opposite to each other, so as to show light in two

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the wooden arms that the former cannot obscure the lanterns as they revolve. The open space in which the lanterns hang when in number 4 position should be about 18 inches high, if large ones are used. But as it may not always be convenient to increase the length of the arm so much, let the ironwork project only 1 foot beyond the end of the wooden arm, and let the latter have a hinge by which about 6 inches of it may double up in order to increase the depth of the open part for the night signals. See fig. 3, in which these hinges are represented.

* The oblique position is of course only recommended when the roof of the signal-house is too small to admit of the indicator lamp-post being fixed vertically, which may sometimes happen.

directions only, are the most proper. But for sea service the pattern called the 'globe lamp,' which was generally adopted in the Royal Navy in lieu of the former signal-lanterns, appears to be decidedly the best. In this, the light is exhibited in every direction, through a very strong globular glass, to which are fitted a copper top and bottom, pierced with air-holes.*

In respect to the dimensions proper for the parts of the Universal Telegraph, we ascertained by experiment that the arms for the day signals should be about 1 foot in length per mile, in order to be distinguished by a common portable telescope of moderate power. This length is computed from the centre of motion to the end of the arm, not including the small part beyond the centre, called the head. By the above rule, a telegraphic arm of 6 feet in length may suffice for stations 6 miles apart; but generally speaking, in telegraphs intended for permanent stations, where the saving of weight is less an object, it may be considered best to add a little to the dimensions thus found.

The width of the arm need not exceed $\frac{2}{13}$ths of its length, and should not be less than $\frac{1}{7}$th or $\frac{1}{8}$th of the same dimension.† The indicator for the day signals should be of the same width, but only $\frac{4}{5}$ths of the arm in length.

The height of the post should be such, that men, or other moveable objects, passing near it, shall not obscure the indicator or arms, when the telegraph is erected on the deck of a ship, or in the field. But when placed on the roof of a permanent signal-house, the projecting part of the post need not exceed the telegraphic arm by more than $\frac{2}{3}$rds of the length of the latter.'

It is desirable in all cases that the telegraphic post should be capable of turning so as to exhibit the arms in various directions.‡ On board ship it must also be occasionally lowered. Hence it becomes necessary to step it upon a simple open circular joint of iron, fixed to the ship's side near the deck, and to secure it by an iron clamp, also of a circular form attached to the rail, nearly in the same manner as the ensign staff of a man-of-war is usually fitted.

The telegraphs hitherto constructed upon this principle are of two sizes; one having arms of $5\frac{1}{2}$ feet in length,§ with the lantern pivots placed $6\frac{1}{2}$ feet from the centre of motion; the other having arms of $2\frac{1}{2}$ feet in length only, with the lantern pivots 3 feet 2 inches from the centre of motion. The former are of a size suited to the largest class of men-of-war. The latter are perfectly portable, as the whole apparatus, including the night indicator, lanterns, &c., does not weigh more than 34lbs. In clear weather, these small telegraphs make signals distinctly at the distance of three miles.

Supposing that telegraphic signals should be required on a sudden emergency, in

* I am informed that Lord Cochrane originally proposed the globe lamp, but the pattern to which I allude is considered an improvement. I have not been able to ascertain the name of the patentee or maker. The large lamps of this description sold in Chatham, and the stage-coach lamps formerly used by the principal proprietors on the Dover road, were both seen distinctly at the distance of 6 miles in clear weather.

† Having fixed the length of the telegraphic arm, there is in the signs exhibited thereby, as in the capital letters of the Roman alphabet, a certain proportional width not only pleasing to the eye, but which cannot be diminished beyond a certain limit without causing the characters to become indistinct. On board ship, where the telegraph may often be seen obliquely, a broad arm is more essential than at the fixed telegraph stations on shore, where this inconvenience seldom occurs.

‡ Because even at permanent stations, not required to make signals in more than one alignment, the power of turning enables the signal-men to adjust the arms and the chains, or other contrivance for moving them when necessary, without needlessly attracting the notice of the corresponding stations.

§ Which corresponds with the size of the Admiralty ship semaphores.

some situation where there may not be time and means for making well-finished telegraphs, in the manner that has been described, I have ascertained by experiment, that the most expeditious and satisfactory arrangement will always be to copy the regular construction, as closely as circumstances will permit. A post, with two planks for the arms, each worked merely by a couple of strings without pulleys, will constitute a day telegraph, and the addition of lanterns, &c., will convert the same simple apparatus into a nocturnal telegraph. In both cases the arms must be counterpoised by wood or iron, and also by weights, but in a ruder manner than was before described. To adopt balls or flags for day signals, or an immoveable rectangular frame, with ropes and pulleys, for supporting the lanterns, for night signals, which are the only other expedients that suggest themselves as a temporary arrangement, will, on trial, be found much less satisfactory than the rudest attempt at the counterpoised telegraphic arm.

It is well known that telegraphs should generally be painted black, and that for permanent stations they should always be erected, if possible, upon heights having no background.*

Of a Telegraphic Dictionary, suited to the Universal Telegraph.

Several Telegraphic Dictionaries have been composed by different authors, but of all that I have seen, the one used in the Royal Navy, which was compiled by the late Rear-Admiral Sir Home Popham,† appears, upon the whole, to be the most judicious. The number of words and sentences contained in it does not exceed 13,000 ; and yet I have seldom observed a deficiency of any useful word. Another author has composed a Dictionary of a similar nature, containing upwards of 31,000 words and phrases ; and a third has composed a work containing more than 140,000 words, phrases, and sentences. It may be observed in regard to this subject, that the extension of a Telegraphic Dictionary beyond a certain limit is an evil, because, in proportion to the number and length of the sentences contained in it, it becomes so much the more difficult to find any of them without a vast loss of time.

Hence the advantages held out by the author of any very voluminous Telegraphic Dictionary must always be in a great measure nugatory, unless the place of every phrase or sentence contained in it could be known by intuition, which is impossible.

It is to be observed, however, that the comparative compendiousness of Sir Home Popham's Telegraphic Dictionary is partly owing to a practice which he has carried to the greatest possible extent, but of which the other authors alluded to have availed themselves more sparingly, or not at all. I mean the system of classing under the same article of his Dictionary, and thereby representing by one common signal, all the forms of the same verb, as well as every noun, adjective, or adverb that happens nearly to coincide in sound, or are connected in signification. Thus the words 'agree,' 'agrees,' 'agreed,' 'agreeing,' 'agreeable,' 'agreeably,' 'agreement,' 'agreements,' would all be denoted by one and the same signal, and comprehended under one article in Sir Home Popham's Telegraphic Dictionary.

It is remarkable how very few ambiguities this sweeping method of classing the words of our language will be found to occasion in practice, as may be ascertained by taking any sentences at random out of a book, and applying Sir Home Popham's telegraphic phraseology to them ; and yet it cannot be denied but that serious mistakes may arise at times from this system.

* Sometimes that inconvenience is unavoidable. Then their colour should form a contrast with that of the background. In certain situations the latter may vary at different periods of the day. In that case it has been found useful to paint the arms white and black in large checkers, each occupying half the width and half the length of the arm.

† And revised by a Committee of experienced Naval Officers.

For example, the phrases—'they are robbing,' 'they are robbed,' and 'they are robbers,' although different in sense, would all be expressed by the same signal in Sir Home Popham's Dictionary. The phrases 'a robber has been executed,' and 'a robbery has been executed,' would also be expressed by the same signal; and the phrases 'they are going,' and 'they are gone,' would likewise be confounded.

It is further to be remarked that Sir Home Popham's Telegraphic Dictionary being necessarily confined to the use of the Royal Navy, is not available for general service; and even if this restriction did not exist, it is evident that if telegraphs were introduced into British India or into any other of our foreign possessions, a number of military phrases and sentences, and a great number of local words and phrases, would require to be introduced, which are not to be found in Sir Home Popham's book; and at the same time it might be desirable to obviate the degree of ambiguity before mentioned in that work. This would require every verb to be expressed in two forms instead of one, and some of the nouns, adjectives, and adverbs now classed under the same head with a verb, or with each other, to be expressed separately. For example, the word *rob* and others connected with it, which are at present all denoted by the same signal, might be divided into three distinct signals in the following manner :—

1st. *Rob*, *robs*, *robbing*, *robbery*, *robberies*, and to follow the same rule in regard to other verbs, including the present tense, the infinitive, and active participle, under the same head, and also any noun of the same sound, or even of kindred meaning, provided in the latter case that it be an action, passion, or any thing inanimate.

2nd. *Robbed*, including always the past tense of the verb and the passive participle under one head, whether they be the same in sound or not.

3rd. *Robber*, *robbers*, and to follow the same rule in regard to personal nouns, keeping them always distinct from the verbs.

It appears also advisable that the adjective and adverb, when different in sound, although of kindred meaning, should likewise be separated from the verb. Hence it would be proper to separate the various words classed under the head *agree*, in Sir Home Popham's Telegraphic Dictionary, as follows :—

1st, *Agree*, *agrees*, *agreeing*, *agreement*, *agreements*.

2nd. *Agreed*.

3rd. *Agreeable*, *agreeably*.

If a select Dictionary on Sir Home Popham's principle were thus dilated, it would in all probability increase the contents of the work from 13,000 to about 25,000 words and sentences; and if the military and local phrases before alluded to were likewise added, it probably might swell the amount to near 30,000. Upon the whole, I conclude that a judicious Telegraphic Dictionary, composed on the most comprehensive plan, so as to embrace every contingency of the public service both at home and abroad, ought not to contain so many as 40,000 articles. This inference may be considered the result of experience, inasmuch as it has been drawn from a careful comparison of the most elaborate works of that nature that I have been able to procure.

Supposing a Dictionary of this description to be composed, I would adapt it to the key of the Universal Telegraph in the following manner :—

The Dictionary should be divided into five parts or classes, each containing one-fifth part of the total number of articles inserted. Thus, for example, if 30,000 articles and 1000 blanks for unforeseen purposes appeared necessary, let each division of the book contain 6000 articles and 200 blanks.

Of the 28 signs which the universal telegraph is capable of exhibiting, I would reject one, namely, position 4 of the day signals, in which one arm points vertically upwards in the direction of the post prolonged; because it has been urged, that unless

when viewed by a very experienced eye, it is liable to be confounded with the post, so as to be mistaken for the position called 'the stop,' in which neither of the arms is shewn.*

Of the remaining 27 signs, *one* should be used as an *alphabetical preparative*, *one* as a *numeral preparative*, and *five* as *dictionary preparatives*, each of the latter referring to its own distinct part or class of the Dictionary.

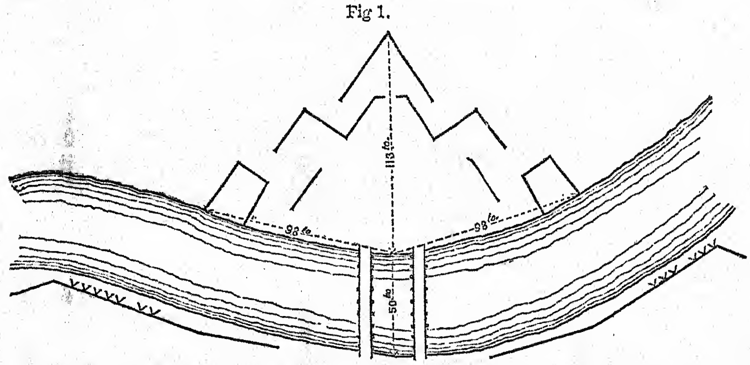
Thus there would be 7 preparatives, and 20 signs for general purposes. Each preparative would of course denote, not only the beginning of that word or sentence which is immediately to follow it, but also the end of the preceding one.

In representing the letters of the alphabet by 20 signs, the letters I and J, the letters K and Q, the letters S and Z, and the letters U and V, would be coupled together; but the letter F would require to be denoted by the two successive letters P H, and the letter X by the two successive letters C S or K S.

The number of signals which may be made by three successive changes on the telegraph, using the 20 disposable signs only, is equal to 8000, being the third power of 20; but as the beginning of each signal must be denoted by a preparative, without which the signal is imperfect, if the above 8000 articles be combined with the five Dictionary preparatives before mentioned, it will be evident that by never using more than four changes on the telegraph for any article of the Dictionary, no less than 40,000 words and sentences may thereby be exhibited; but, as remarked before, this number is greater than appears to be absolutely necessary in a judicious and well-composed Telegraphic Dictionary.—C. P.

TÊTE DE PONT.—Bousmard says a *tête de pont* ought to unite the properties of a perfect defence of the river on both sides, to cover the bridge well, with space sufficient to contain the garrison, and furnish a free passage of a considerable body of troops, affording also facilities for their advance or retreat; of which fig. 1 is a good example.

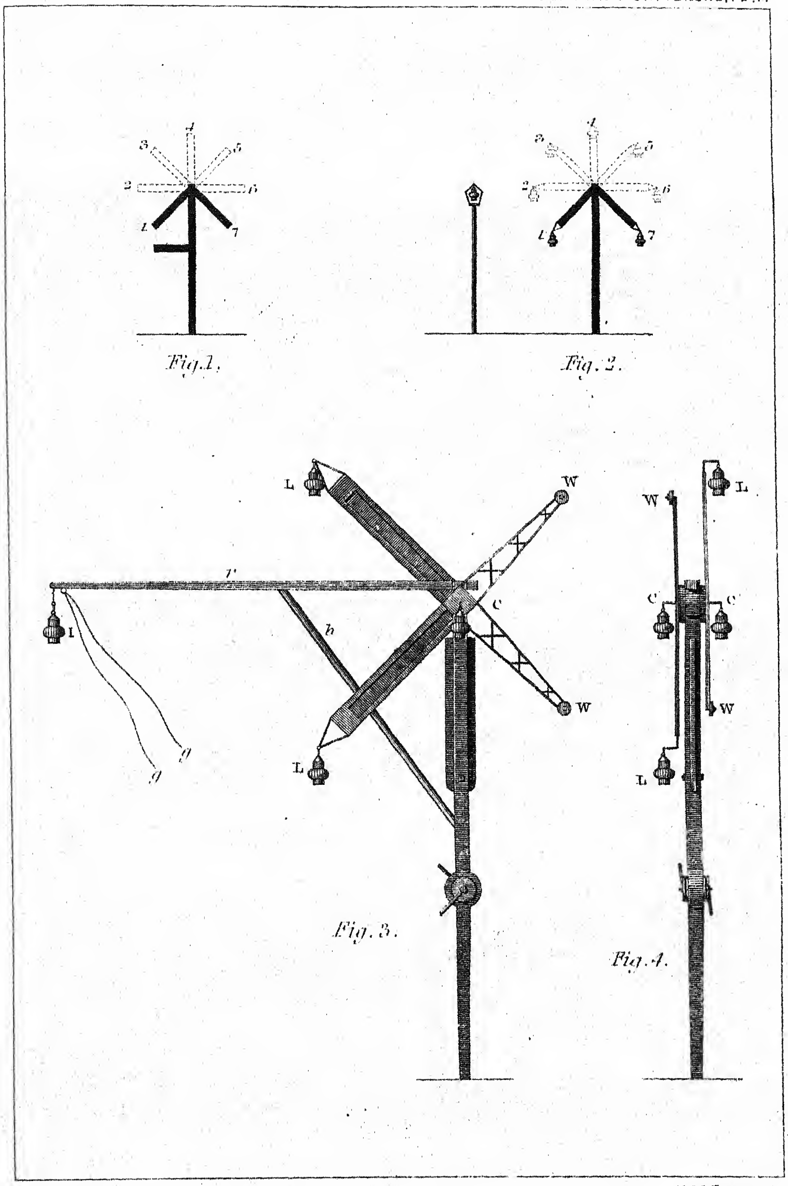
Fig 1.



The *tête de pont* should also be of itself sufficiently strong to resist an assault.

The construction will very much depend upon the nature of the ground and the

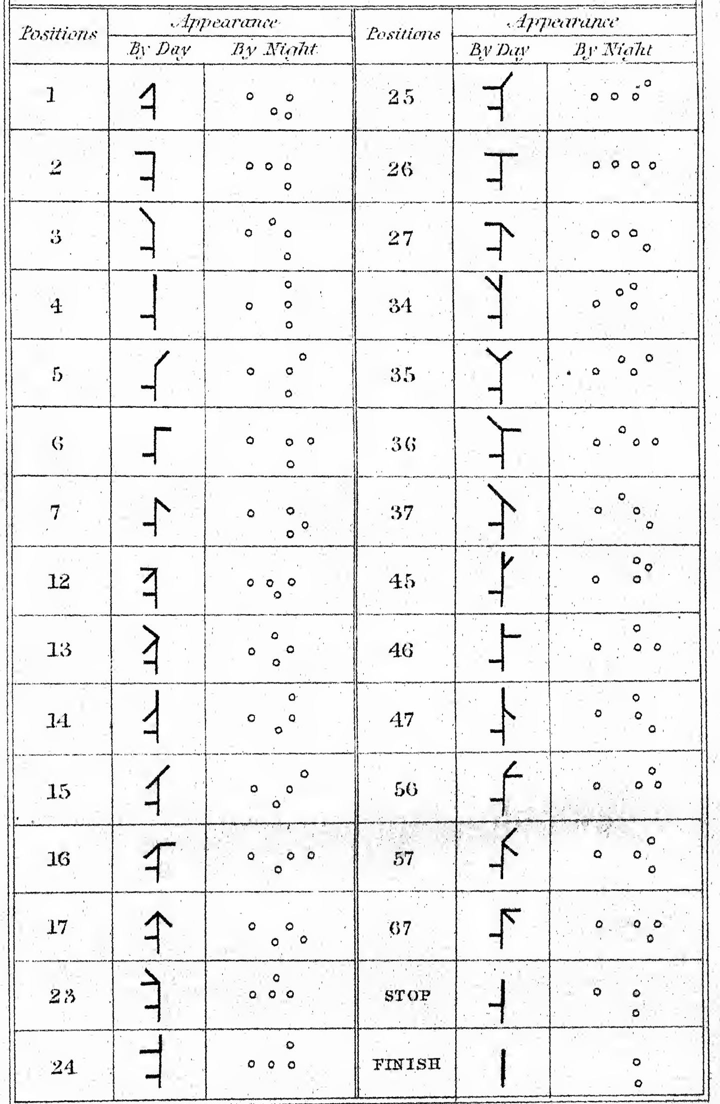
* This sign is used to mark the end of a word when several successive signals are all made alphabetically. In the stop the indicator appears nearly equal in length to the upper part of the post. In No. 4 position it is not quite half so long as the same part of the post appears to be when prolonged by the addition of the arm. Hence the experienced or careful observer will scarcely mistake between these two. No. 4 of the night signals is one of the most conspicuous signs.



J. W. Lowry fc.

London John Weale High Holborn 1851.

TABLE OF THE SIGNS OR COMBINATIONS.

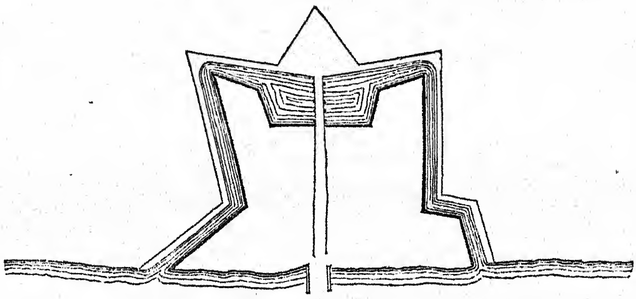


J. W. Lowry fc.

London; John Weale, High Holborn, 1851.

object in placing the bridge, whether for a permanency or for temporary purposes: if the former, some care must be taken in the construction, and if the ground is very low, the ditches may be wet, as explained in fig. 2.

Fig. 2.



Works to cover bridges of stone or wood, of a permanent nature, may be made of some existing buildings, loopholed and barricaded on both sides of the river, and artillery planted on the near side of the river to flank and protect the advanced works; the object being to prevent any small bodies of the enemy destroying the bridge, and thus interrupting the communication. Fig. 3 is another example of a permanent bridge-head with wet ditches on a more extended scale.

Fig. 3.

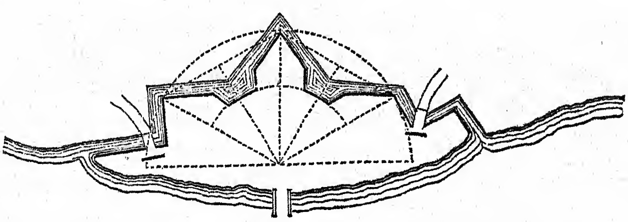
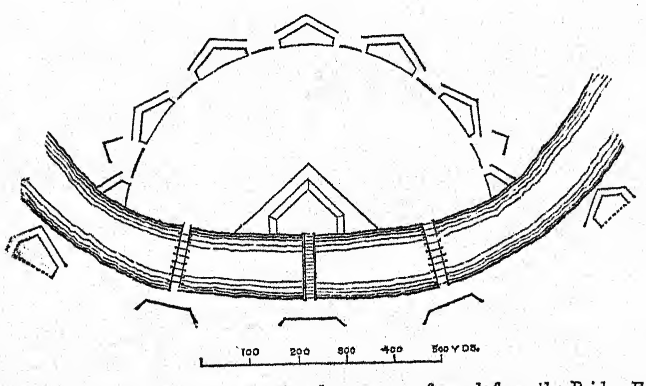


Fig. 4 represents the plan of a *tête de pont* combining the more permanent with the temporary, for the passage of a large army, having three bridges to cover, of

Fig. 4.



which two would be temporarily laid for the purpose, formed from the Bridge Equip-

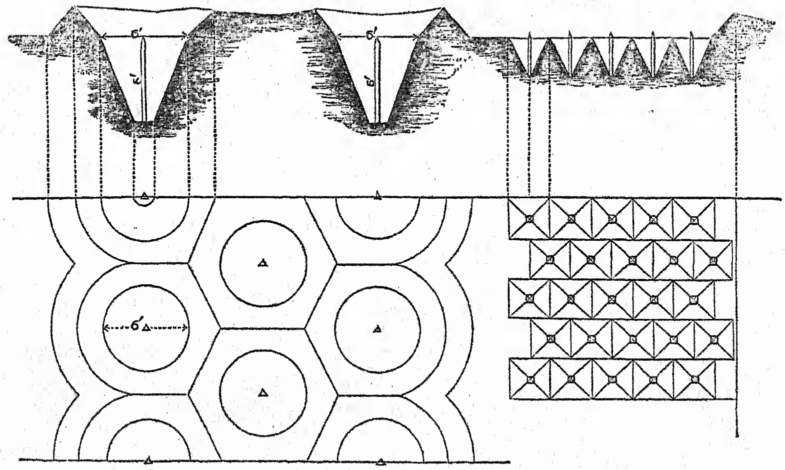
ment of the Army, and which would be removed when the troops had passed, whilst the centre one would be so far permanent as might be necessary to secure the communication and supplies, and formed of materials obtained on the spot; and the inner bridge-head constructed with more care than the outer works. Emplacement for Field Artillery would be prepared on the near side of the river to flank the works of the *tête de pont.*

For the construction of works of this nature, see the article on 'Fortification, Field,' as the rules explained therein apply equally to the *tête de pont.*

The following should be attended to in the selection of sites as well as in forming the works:

The bridge-head should admit of a defence until all the troops have passed. It should cover the bridge from the enemy's artillery. If there are islands in the river, they may be fortified with advantage.—G. G. L.

TROUS DE LOUP.—The application of *trous de loups* has been already explained in the article 'Fortification, Field,' in an extract from 'Memoranda on the Lines before Lisbon, in 1810,' by the late Major-General Sir John Jones, Bart.: their construction is represented in the annexed figure.—(See vol. ii. p. 27.)



V.

VOLTAIC ELECTRICITY.*

The essential parts of an electric telegraph are the following:—

1st. *The Source of Electricity.*—This may be a voltaic battery, or a magneto-electric machine; the former is more usually employed.

2nd. *The Conductor*, which is composed of a metallic wire connected with the source of electricity and with the instruments to which it conveys the electricity, and so insulated from other conductors that the electricity will pursue the desired course with the least possible loss, when the voltaic circuit is completed, either by a second wire, or, as is invariably done in practice, by connection with the earth at each end.

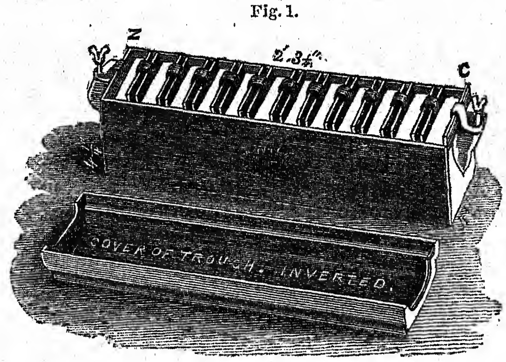
* By Captain Schaw, R.E.

3rd. *The Instruments*, which must each consist of two parts, one for receiving the currents of electricity and making evident to the senses the signals which they convey, the other for transmitting signals to distant stations.

1st. *The Source of Electricity.* Various descriptions of voltaic batteries are in use for the purpose of telegraphy. That known as Wollaston's battery was at first generally employed, but it has now given place to other forms which are superior to it in the constancy of the currents they produce.

In cases where portability is a desideratum, however, the Wollaston battery is still used; the ordinary form is shown in Fig. 1, twelve cells being united in a trough,

Fig. 1.



made of gutta-percha, the plates are alternately copper and zinc, the latter amalgamated with mercury, and are $3\frac{1}{2} \times 4\frac{1}{2}$ inches, the cells are lled with fine silicious sand (free from carbonates), and moistened with sulphuric acid diluted with water in the proportion of $\frac{1}{15}$. This battery developes a powerful current of electricity when first made up, but it is very inconstant, and after being in use for a certain time, varying according to circumstances, it loses its power from various causes, the sand must then be washed out, and the battery made up again with fresh solution and the zincs re-amalgamated.

The great defect of the simple combination of zinc and copper in dilute acid, is that the bubbles of hydrogen gas resulting from the decomposition of the water by the electric force, adhere to the copper-plate, and being very bad conductors of electricity, the power of the battery is very rapidly diminished when it is put in action; moreover, the hydrogen being in what is termed the nascent state, combines very readily with the oxygen of the sulphate of zinc, produced by the action of the battery, and metallic zinc is thus deposited upon the copper-plates, and so, similar metals being opposed to each other, the action of the battery ceases. Many methods have been adopted to get rid of the hydrogen. In Grove's and Daniel's batteries it combines with the oxygen of the solution in which the electro-negative metal is immersed. In Smee's, and its kindred forms of battery, the hydrogen is assisted in escaping from the negative plate by giving it a rough surface presenting a multitude of small points from which the bubbles separate easily.

The sand is chiefly useful to prevent the acid from spilling when the battery is moved about, it tends also to make the action of the battery more regular; but it should not contain carbonates, such as carbonate of lime, or a chemical action takes place with the sulphuric acid which is detrimental to the battery.

In the best form of this battery a small gutta-percha pipe is inserted in each cell, extending down to the bottom; through this, fresh diluted acid is poured in from time

to time to make up for waste by evaporation. By thus introducing the fresh acid at the bottom of the cell, where the heavy sulphate of zinc gravitates, a more regular action is obtained. If the sulphate of zinc be allowed to accumulate in the lower part of the cell, a cross voltaic current is established between the upper and lower portions of the plates which are in solutions of different strengths. The effective current in circulation is thus diminished, and the upper portions of the zinc plates are rapidly dissolved away.

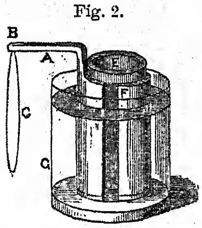
	lbs.	oz.
The weight of the battery is (without sand or liquid) . .	14	14
,, ,, with sand	22	0
,, ,, sand and liquid	23	12½

it requires about 1lb mercury and 2 pints acid per annum.

In America "Grove's" battery is extensively employed. This is the most powerful form of battery, producing currents of electricity of great quantity and intensity, but it does not appear to be well adapted for the purposes of telegraphy, as it is very expensive and troublesome to keep in order; and by using a few more cells of a less energetic, but simpler and cheaper, and at the same time more constant, battery, we can produce an electric current of sufficient intensity to overcome the resistance due to long wires, and having at the same time a sufficient quantity to influence effectually the delicate instruments used in telegraphy.

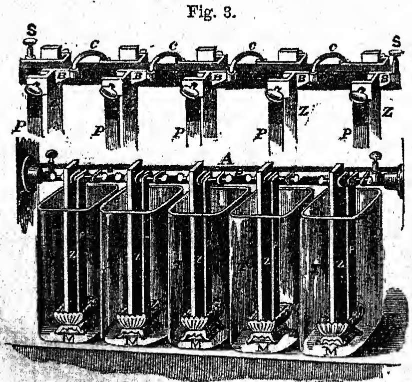
Fig. 2, shows the form of Grove's battery used in America: E is the porous earthenware cell containing pure nitric acid, it is 3¼ inches high and 1¼ inch in diameter. In this cell the strip of platinum foil, C, is immersed; it is soldered at B to the projecting arm A of the zinc cylinder F. The zinc is about 4 inches high, and 3 lbs. in weight, it is placed in the glass cell G, containing dilute sulphuric acid in the proportion of $\frac{1}{30}$. To keep this battery in effective action it is necessary to take it to pieces every night and to clean the zinc plates, and to add $\frac{1}{10}$th pure nitric acid every morning. The dilute sulphuric acid is renewed twice a week. The zincs require renewal every three months. (Shaffner's "Telegraph Manual.")

Fig. 2.



"Smee's" battery is the cleanest and most generally convenient form for experimental purposes, but it is too expensive to be employed generally as a source of electricity for the telegraph, and the platinised silver plates require very careful handling.

Fig. 3.



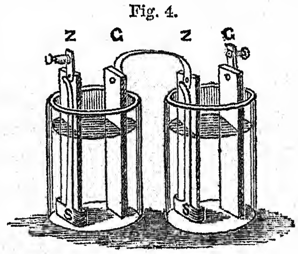
A modification of Smee's battery, known as Chester's battery, is, however, used largely in America; it is shown in fig. 3. The form is simple and convenient, and it has been adopted for the local batteries of the government telegraphs in Australia.

A, is a bar of varnished wood, or other insulating material, from which the plates of zinc and platinised silver Z and P are suspended by the clamps and binding screws B B. The zinc and platinised silver plates are sometimes placed on opposite sides of

the bar A, as in the upper figure; T T are the glass cells containing dilute sulphuric acid. The zinc plates stand in cups of mercury M M, and their amalgamation is thus ensured. This form of battery requires to be taken to pieces, the zinc plates cleaned, and the solution renewed about every three months. The zincs generally last a year, and the platinised silver, if carefully handled, will last many years.

Another battery on the principle of Smee's, which is very powerful and moderately constant, is obtained by a combination of platinised graphite and amalgamated zinc. This battery has been substituted for the Wollaston, or sand, battery, on the London and South Eastern Railway, and answers well. It is shown in fig. 4. The slabs of graphite (which is carbon in a nearly pure condition) are obtained from the refuse of gas works; some difficulty is experienced in cutting them to the required form, and the graphite and copper connecting bands must be tinned at the points of junction to ensure the adhesion of the solder.

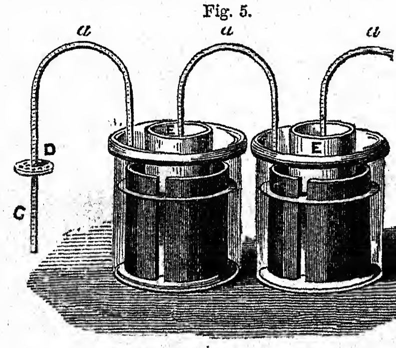
Fig. 4.



The first manufacture of these batteries, and their repair when the zincs are worn out, are somewhat troublesome; but when the necessary appliances are at hand they can be cheaply made, and are being largely introduced into use for telegraphic purposes. They are made of two sizes according to the purpose for which they are required. A few cells of the larger size, in which the plates are $7\frac{1}{2}'' \times 3''$ in quart jars, being used for local batteries when electricity of quantity is required; and a larger number of the smaller size plates, $6'' \times 2''$ in pint jars, for the main current on the line. The zincs are amalgamated and placed in gutta-percha slippers S S, filled with mercury. This arrangement keeps up the necessary supply of mercury to prevent local action. For full description, *vide* "Walker's Electrotype Manipulation," Part I.

Daniel's constant battery is the most generally used in England, and on the continent of Europe. The arrangements of the different parts of the battery vary considerably. The form generally adopted for the French telegraphs is shown in fig. 5. The French battery is made of two sizes; in the smaller the zincs are about 12 centimetres high, in the larger they are about 20 centimetres in height; the former are used for the line current, and the larger for the local batteries. The copper elements D, being in contact with the porous cells, the latter become encrusted with metallic copper after some time, and must be renewed every six months on an average.

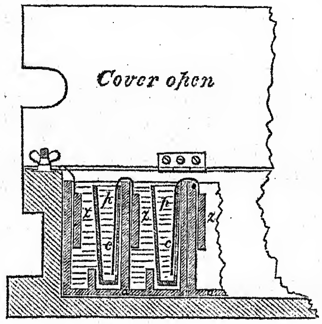
Fig. 5.



To put the battery in action the outer cell is first filled with simple water, and the porous cells E with a saturated solution of sulphate of copper, some crystals of which are left on the perforated copper disc D; after a short time some of the sulphate of copper passes through the porous cells, and diminishes the liquid resistance in the outer cells, but at the same time copper is precipitated as a black powder upon the zinc. This, however, does not materially affect the working of the battery, which is very constant.

Fig. 6 shows a longitudinal section through one end of Muirhead's battery, the form of Daniels' battery now generally used for telegraphs in England. The endosmosis through the porous cells is checked in a great measure by greasing them, except on the portion which is opposite to the zinc plate; this increases the liquid resistance and reduces the power of the battery somewhat, but it is conducive to economy, effecting a saving of 40 per cent. in sulphate of copper. The zinc plates are about 4″ × 2″, the copper plate is about 4″ × 3″. The porous cells, P P, are filled with crystals of sulphate of copper and water; a very dilute solution of sulphuric acid in water is used in the outer cells, O O, which are of white porcelain, and are made in pairs. Five such pairs are enclosed in a strong wooden box with a cover, as shown in the figure.

Fig. 6.



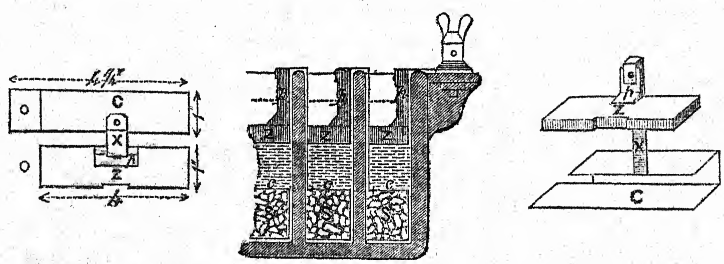
At Chatham a modified form of Daniel's battery without porous cells is used. The battery is arranged in a gutta-percha trough containing twelve cells, such as is usually employed for the zinc and copper "sand battery" shewn in fig. 1.

The copper plate (*c*, fig. 7) is placed below the zinc plate (*z*) in each cell, and the copper is bent in the form shown in the drawings, crystals of sulphate of copper (*s*) being placed between the two "leaves" of the copper plate.

A portion is cut off one end of the upper leaf of the copper, and the zinc is made to correspond in size with the upper leaf, leaving a small space (*o*) at the end of the plate, through which the crystals of sulphate of copper can be dropped in from time to time.

The zinc plate is cast in the form of a parallelopipedon, with a projection (*p*), to which the copper strip is rivetted, which connects it with the copper plate. Sometimes "rolled zinc" is used, and in this case the plates are cut out of the sheet with

Fig. 7.



projections similar to *p*, which are bent up after heating the metal to about the temperature of a tailor's "iron." Rolled zinc is considerably more electro-positive than cast zinc, and its employment increases the electromotive force in the proportion of about 3 to 2.

The liquid used is ordinary water, which soon dissolves some of the sulphate of copper, the battery is then ready for use, and continues in action with remarkable constancy for a great length of time. The zinc plates are placed above the copper plates in order to take advantage of the two strata of fluid which form in each cell. Sulphate of copper is heavy, and gravitates chiefly to the bottom of the cell, and sulphate of zinc, which is soon formed by the action of the battery, and which is lighter

than sulphate of copper, remains chiefly in the upper portion of the cell, and thus each metal is in a solution of a sulphate of itself. A certain amount of sulphate of copper mixes with the sulphate of zinc, however, and copper is deposited on the zinc in the form of a black powder, but this does not appear to diminish the power of the battery.

This form of battery is very compact and convenient, and owing to the reduction of resistance resulting from doing away with the porous cells, it is quite equal in power to the large Muirhead battery, although the mean sectional area of the liquid between the plates is not more than 4–10ths as large, but the copper from the solution is reduced upon the zinc more rapidly, and it is therefore somewhat more expensive in sulphate of copper. This is, however, more than counterbalanced by the suppression of the fragile and cumbrous porous earthenware cells.

These batteries ordinarily maintain an electric current of equal force for a year, crystals of sulphate of copper occasionally being dropped into the cells through the spaces (o) left at the ends of the zinc plates and the upper leaves of the copper plates. The zincs are then worn out and must be renewed, which is a simple and inexpensive operation.

	lbs.	oz.
The weight of this battery, without liquid, is . .	10	6
,, ,, with liquid . . .	16	6

About 4 lbs. of sulphate of copper are required to keep it in action for a year at 5*d.* per lb. The first cost of the battery is about 25*s.*

It is not found necessary to amalgamate the zinc plates in any of the forms of the Daniel battery used for telegraphy, as strong acid solutions are never employed. In the form used at Chatham the amalgamation would be injurious, as the mercury would fall on to the copper plates and produce two similar metallic surfaces opposed to each other.

In determining the size, number, and mode of combining the elements of a particular form of voltaic battery to effect any special object, the theory of Ohm is of very great assistance. By this theory the equation $Q = \frac{T}{L + w}$ expresses the constant relation between the elements of the source of electricity and the work done. Q = the quantity of electricity in circulation, which may be measured by the deflection of a galvanometer, the decomposition of water, or the heating of a wire, as found most convenient. T = the electromotive force or tension of one pair, or element of the particular voltaic combination; it may be measured directly, when a number of elements are combined in series, by the effects of electrical attraction or repulsion, as shewn by an electrometer; but no instrument has yet been constructed sufficiently delicate to measure directly the static electrical tension of *one* element of a voltaic battery. The electromotive force depending solely on the metals and liquids employed in that combination, is a constant for each battery. The size and distance apart, and number of the plates and other special arrangements of the combination, do not affect this electromotive force, although they do materially affect the effective force in circulation.

The electromotive force of a Daniel battery, for instance, depends entirely upon the excess of the affinity of the zinc for the oxygen of the water, above the sum of all the other affinities in the combination, viz., of the copper for the oxygen and sulphuric acid, and of the hydrogen for the oxygen.

L = the liquid resistance or resistance to the passage of the current of electricity from the zinc to the copper in each cell. This is made up of the resistance of the liquid, and of the porous cell, and of the plates themselves. The last may generally be neglected, it is so small, although it shews the necessity of perfect metallic connections between the pairs of plates. The resistance of the porous cell varies directly as its thickness and the closeness of the texture, and inversely as its surface interposed between the metals. The resistance of the liquid varies directly as the distance

apart of the plates, and its specific resistance, and inversely as the opposed surface of the plates or sectional area of the liquid prism between them.

$w =$ the resistance of the conductor, which varies directly as its length and as its specific resistance, and inversely as its sectional area.

And here two terms, which are of frequent occurrence in speaking of voltaic electricity, require to be defined—*quantity* and *intensity*.* Upon the *quantity* of electricity in circulation depends the amount of work done, whether it be the decomposition of water, the deflection of the needle of a galvanometer, the heating of a metal, or any other effect of dynamic electricity; and upon the *intensity*, or *tension* under which the electricity is generated, depends the quantity which can be put in circulation in a given time through a conductor of a fixed resistance.

In the equation $Q = \frac{T}{L + w}$, if $w = o$, that is, if the plates be connected by a conductor whose resistance is insignificant, then $Q = \frac{T}{L}$ representing the quantity of electricity in circulation in a voltaic pair or element of a voltaic battery, when $w = o$.

If n such elements be arranged in series, connecting the positive metal of each with the negative of the next, and the first positive and the last negative metals be connected by a conductor of insignificant resistance, we have n electromotive forces, and also n resistances, and the value of Q will remain unchanged for $Q = \frac{n\,T}{n\,L} = \frac{T}{L}$; whence we learn that, in cases when the external resistance is very small, little or no advantage will be derived from multiplying elements in series; but if the external resistance be considerable, the case is very different, with n elements so connected we can introduce n times as much external resistance without diminishing the quantity of electricity in circulation, as will be seen from the equation $Q = \frac{T}{L + w} = \frac{n\,T}{n\,L + n\,w}$.

The quantity of electricity in circulation may be increased by diminishing either term of the denominator of the fraction $\frac{T}{L + w}$.

L may be diminished by approaching the plates nearer to each other; but to this there is a practical limit, owing to various causes; it may also be diminished by increasing the surface of the plates, and with them the area of the conducting prism of intervening liquid, and this increased surface may be obtained either by enlarging the plates or by connecting the positive plates of several pairs together, and also their negative plates.

w may be diminished by decreasing the length or increasing the sectional area of the wire, or, which comes to the same thing, by combining a number of elements in series.

$$Q' = \frac{T}{\frac{L + w}{n}} \;.\;.\;.\; (1)$$

$$Q'' = \frac{T}{L + \frac{w}{n}} \;.\;.\;.\; (2) = \frac{n\,T}{n\,L + w} \;.\;.\;.\; (3).$$

(1) Representing the increase due to diminished liquid resistance.
(2) Representing the increase due to diminishing the wire resistance.
(3) Representing the same increase by the combination of elements in series.

The comparative values of Q′ and Q″ evidently depend on the comparative values of L and w. If the liquid resistance be in excess of the external wire resistance, it will be best to increase the size of the plates, but if the external resistance be in excess,

* The word "intensité" is used by French writers in the same sense as we use the term quantity.

and that it cannot be directly diminished, Q may be most economically increased by arranging the battery in series of elements.

In the practical service of the electric telegraph, the currents passing between distant stations meet with very considerable resistance due to the conducting wires and the coils of fine wire in the instruments, while the liquid resistance in each element of a Daniel's battery on Muirhead's pattern is only equal to about a mile of ordinary conducting wire; hence it is necessary to arrange the elements in series to obtain the required force in circulation.

For local circuits which have but a small wire resistance, but in which it is required to circulate a considerable quantity of electricity to work the electro-magnets, batteries are used of a few elements in which the liquid resistance is diminished by enlarging the plates.

The comparative electromotive force and liquid resistance of various forms of battery used in telegraphy, as determined by experiments by Captain Schaw and Lieutenant Fowler, are as follows in miles of resistance of No. 16 pure copper wire:—

	T.	L.
Graphite battery, plates 6″ × 2″	4·56	·38
Ditto in action for two days	4·96	·63
Muirhead's Daniel-plates, 4″ × 2″ and 4″ × 3″	4·36	·85
Ditto (greased cells) ditto	4·34	1·24
Chatham battery, plates 4 × 1, *cast zinc*	4·28	·84
Sand battery, plates $3\frac{1}{2} \times 4\frac{1}{2}$, freshly made up . . .	4·56	·53

The liquid resistances vary with the sizes and arrangements of the metals opposed to each other in the batteries, but will always be greatest, *cæteris paribus*, in those which require porous cells; hence the reason will be apparent why the force circulated by the small battery used for the R. E. telegraphs is equal to that derived from the large Muirhead's battery with the porous cells.

The superior constancy of Daniel's over Smee's, or the platinised graphite battery, and its advantages over Grove's battery in greater constancy, diminished cost, absence of noxious fumes, and simplicity of arrangement, justify its very general adoption as the best battery for the electric telegraph in which currents of a constant force having considerable intensity but small quantity are required, while the peculiarly compact and simple form used at Chatham, requiring no porous earthenware cells, no mercury nor any acids, but only the dry crystals of sulphate of copper to be carried with it, appears to be in every way the best suited to military purposes. In operating through long circuits, when many cells are combined in series to overcome the resistance, and the electrical tension is considerable, it becomes important that the batteries should be well insulated, or the electricity may escape to the tables on which they are placed. On shorter lines the tension is so low that this precaution becomes of less importance.

Magnetic Electricity.—Permanent magnets are frequently used as sources of electricity instead of voltaic batteries, advantage being taken of the discovery of Dr. Faraday that if a coil of insulated wire be wound on a soft iron core, and this soft iron be magnetised, a momentary current of electricity is induced in the wire, and a corresponding current in the opposite direction takes place at the moment when the soft iron loses its magnetism or when its polarity is reversed. Magnetic machines have been constructed on these principles, and it was thought by some that the voltaic battery with all its inconveniences might be discarded for telegraphic purposes, and that magnetic electricity thus developed would entirely supersede it.

This anticipation has not been fully realised. For the purposes of electro-metallurgy

magneto-electricity is very largely employed, but for electric telegraphs it has not been found generally so satisfactory as voltaic electricity. This is due chiefly to the high degree of tension under which the electric force is developed by this means, rendering it imperatively necessary that great perfection shall be preserved in the insulation of the conducting wires—a condition very difficult of fulfilment in practice. The British and Irish Magnetic Telegraph Company, when their lines were first opened, made use of magnetic electricity exclusively, and this system is still used, I believe, in some parts of Ireland; but on all their lines in England the magnets have been given up, and voltaic electricity has been substituted, the reason given for the change being the increased rapidity of signalling, and the diminution of the difficulties due to defective insulation, resulting from employment of voltaic electricity.

In Australia, magnetic electricity is almost exclusively employed for the long lines of telegraph lately erected there, and it has been found to work well. This may perhaps be accounted for by the dryness of the climate, which is peculiarly favourable to insulation.

Magnetic, letter-showing, telegraphs are now largely used in London and other large towns by mercantile houses, for communicating between their various offices and warehouses. The distances being short, perfect insulation is not difficult of attainment, and the convenience of dispensing with the voltaic batteries is very great in such cases.

For military purposes, however, it appears exceedingly doubtful whether electricity of such high tension, and requiring such perfect insulation, can be safely employed.

Conductors.—These may be divided into two classes—wires suspended in the air on insulated supports, at intervals, and wires entirely coated with insulating material, and either submerged under water or buried underground.

In the infancy of Electric Telegraphy two insulated wires were considered necessary for each circuit, but it was soon found that one insulated wire was sufficient to insure the electricity pursuing the desired route, and that the electric circuit would be complete if one pole of the battery and the extreme end of the conductor were put in communication with moist earth, the other pole of the battery being connected with the wire.

A controversy still exists as to whether a current of electricity really passes back through the earth, or whether the earth acts rather as a great reservoir always ready to receive or impart electricity. The latter view appears to be more correct when the distance is great; the former may in part be true when the distance is very small. Moist earth offers a very much greater resistance than copper wire, in the proportion of about 32,000,000 to 1. Hence the extent of metallic surface in contact with moist earth, necessary to produce the best results in each case, will depend upon the tension and the quantity of electricity to be circulated. If the tension be great, and the quantity small, as is eminently the case with frictional electricity, and in a lesser degree with the induced currents derived from either voltaic or magnetic sources, a very small surface will be sufficient; but, on the other hand, if quantity currents are to be circulated with comparatively low tension, as in the case of exploding mines by heating a platinum wire, so large a metallic earth connection would be required to reduce the resistance sufficiently, that a return wire is very much more convenient. In Telegraphy, currents of comparatively high tension are required to overcome the resistance of long wires, and the quantity required to influence the instruments is very small; hence, earth connections become most valuable. Careful experiments made by Matteucci showed that with very perfect earth connections at a distance of 40 miles, the resistance of the earth became so insignificant, compared with that of the wire, as to be quite negligible, and the electrical resistance was practically one-half of what it would have been had two wires been used. In towns, advantage is taken of the gas and water-pipes for the earth connection; but where these are not available,

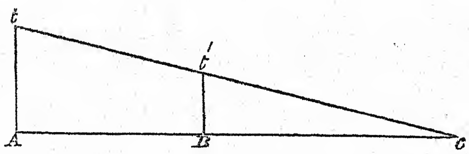
it is found that four square feet of copper plates buried in moist earth is practically sufficient.

But it is important that the earth plate be buried in *moist* earth, or the resistance will be so great as materially to reduce the quantity of electricity in circulation.

The resistance due to the earth connection being represented by r, the quantity of electricity in circulation through a mixed circuit of voltaic battery, wire, and earth will be $Q = \frac{n\,T}{n\,L + w + r}$, from which it will be evident that to increase Q we must diminish r, and that as T increases so r may be increased without diminishing Q.

Before proceeding to describe the various conductors in use, it will be best to state the laws of the propagation of currents in long conductors. *Currents* of electricity are solely due to differences of tension. In a voltaic battery the negative and positive poles have opposite tensions, which diminish regularly to the central point of the battery, where they neutralize one another, and as long as the poles are not connected, this difference of tension remains as a static force. If the central point be connected with the earth, no alteration takes place; but if one pole be connected with the earth, its tension becomes 0, and that of the other is doubled, the tensions increasing regularly from one pole to the other. If the poles are connected by a short thick wire, the whole quantity of electricity generated is circulated through the wire, a constant current taking place, and all apparent tension ceasing. If the wire be very long, a current of small quantity is circulated, and the tensions are slightly reduced, and distributed throughout the length of the wire in precisely the same manner as in the battery.

The case is similar in a telegraph wire. If A and C represent two telegraph stations connected by an uniform conductor, A C, and if the current starting from A has a tension $= A\,t$; at B, half-way to C, the tension will be $B\,t'$ (half $A\,t$), and at C it will be 0, the diminution of the tensions being accurately represented by the line t C. This will be evident from the following considerations. The quantity of electricity in circulation is equal throughout the circuit, as shown by the equal deflections of a galvanometer when inserted at any point. If the wire be divided at B, and it be required to circulate the same force through B C as was before circulated through A C, we have in one case $Q = \frac{n\,T}{n\,L + w}$, in the other, $Q = \frac{\frac{1}{2}n\,T}{\frac{1}{2}n\,L + \frac{1}{2}w}$, only the half tension being required to circulate the same quantity through half the resistance. Mr. Latimer Clarke has proved the truth of this law by actual experiment on long telegraph lines. (*Vide* his Report in the Parliamentary Report on Submarine Cables.)



The electrical resistances of conducting wires vary as $\frac{l\,s}{d^2}$, l being the length, s the specific resistance of the metal, d the diameter of the section of the wire. When a conducting wire is coated with an insulating material, a second resistance is opposed to the passage of the current, due to induction. The wire becomes charged with electricity in the same manner as a Leyden jar, the wire acting as the inner metallic coating, the insulating envelope as the glass, the water or moist earth or outer protecting sheathing as the outer metallic coating of the jar; and although the electrical tension be comparatively low, the amount of surface is so large in a long cable that the flow of electricity through the conductor is retarded in a very material degree.

The same effect is produced in long wires suspended in the air, but in so much a smaller degree as not to be generally noticed. Fuller details on this subject will be found in an extract from the Report of the Submarine Telegraph Committee, but the laws experimentally established by their investigations are as follow :—

1. The inductive charges of insulated cables, when the same insulating material is used, vary, as $\frac{l\sqrt{d}}{\sqrt{t}}$, where l = length of cable, d = diameter of conductor, t = thickness of insulating envelope.

2. The inductive capacities of different insulating materials differ considerably; for instance, a greater inductive electric charge is produced under similar circumstances in a cable insulated with gutta percha than in a cable insulated with india-rubber.

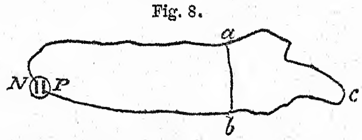
3. The distribution of the inductive charge in a cable is not equable : the amount of induction at every point in the conductor varies directly as the tension at that point.

4. The velocity of the current is not increased by increased battery power, because as the tension increases so does the induction and consequent retardation of signals.

5. The time required to charge with electricity or to discharge an insulated wire, and upon which depends the rate of signalling, appears to vary as the square of the length, but this point is not well ascertained. The great difficulty to practical telegraphy in long submarine cables arises from the fact that the time occupied in the discharge from the far end of the cable is much longer than that required for charging it by the battery, so that a signal which is short and distinct at the near end of the cable will ooze out gradually from the far end. The time occupied in travelling through 1500 miles of insulated underground wire was found by Professor Faraday to be about two seconds. About the same interval was observed in the tests of the Atlantic cable, 2500 miles long; but the rate of signalling through the cable was not more than from 1·1 to 2·5 words per minute (each word having five letters on an average.

*Law of divided currents.**—If N and P be the two poles of a source of electricity,

Fig. 8.



and N a b P a conducting wire, and if at a and b a second wire, $a c b$, be connected, the laws governing the currents of electricity circulated through these conductors, are as follows :—

Let T be the tension or electromotive force of the source of electricity ;
R the resistance of the source and the conductors N a, P b ;
r ,, ,, conductor $a b$;
r' ,, ,, ,, $a c b$.

To determine the force or quantity of electricity circulating—

1. Through the circuit N $a b$ P before the wire $a c b$ is connected (called by the French the *primitive* current) ;

2. Through the entire circuit, including both wires (called by the French the *principal* current) ;

3. Through the wire $a b$ (called by the French the *partial* current) ;

4. ,, ,, $a c b$,, ,, *derived* current) ;

Let Q, Q′, q, q', denote these forces respectively ; then,

1. The resistance of the circuit N $a b$ P being R + r, we have $Q = \frac{T}{R + r}$ (the *primitive* current).

* This investigation is taken from Gavarret's work on Electricity.

2. The resistance of the wires $a\,b$ and $a\,c\,b$ being r and r', their conductivity will be evidently represented by $\frac{1}{r}$ and $\frac{1}{r'}$ respectively, and their joint conductivity by $\frac{r + r'}{r\,r'}$, and, consequently, their joint resistance by $\frac{r\,r'}{r + r'}$. Hence, the resistance of the whole circuit will be in this case $\mathrm{R} + \frac{r\,r'}{r + r'} = \frac{\mathrm{R}\,(r + r') + r\,r'}{r + r'}$,

and $\mathrm{Q}' = \frac{\mathrm{T}\,(r + r')}{\mathrm{R}\,(r + r') + r\,r'}$ (the *principal* current).

3. Since the quantity of electricity in circulation is equal at every point in the circuit, and the tensions at different points vary as the resistances, t, the difference of tension between a and b, will be proportional to the joint resistance of the two wires, $a\,b$ and $a\,c\,b$,

$$\text{Or,}\quad t : \mathrm{T} :: \frac{r\,r'}{r + r'} :: \frac{\mathrm{R}\,(r + r') + r\,r'}{r + r'},$$

Whence $t = \frac{\mathrm{T}\,r\,r'}{\mathrm{R}\,(r + r') + r\,r'}$. This tension is common to the two wires $a\,b$ and $a\,b\,c$, we have, therefore,

$$\text{For } a\,b \quad q = \frac{t}{r} = \frac{\mathrm{T}\,r'}{\mathrm{R}\,(r + r') + r\,r'} \text{ (the \textit{partial} current).}$$

4. And for $a\,c\,b$ $\quad q' = \frac{t}{r'} = \frac{\mathrm{T}\,r}{\mathrm{R}\,(r + r') + r\,r'}$, (the *derived* current).

From the consideration of equations (3) and (4) it will be apparent that *when several routes are given to a current of electricity, it divides itself in the inverse proportion of the resistances opposed to it.* This general law is of the greatest practical utility in numerous cases connected with the service of the electric telegraph. When a telegraph line is imperfectly insulated, it explains to us how the current is gradually enfeebled, as it approaches the distant station, in *quantity* as well as in tension. If the earth connection in a telegraph station be imperfect, and several instruments be in connection with the same earth wire, as is the usual practice, it explains to us the reason of all the instruments being set in motion when only one is sending or receiving, the current dividing itself amongst the various channels open to it, in the inverse ratio of their resistances. These, and various other causes of perturbation in the working of electric telegraphs, are fully investigated in Gavarret's valuable treatise on the subject.

The resistance offered by the conductor to the passage of the electric current is a most important consideration, and for the comparison of the resistances offered by different conductors, various standards have been proposed; that of M. W. Siemens is probably the most perfect, viz. a cylinder of pure mercury, at the temperature of zero centigrade, one mètre in length, and with a sectional area of one square millimètre; German-silver wire is compared with this standard and used in a rheostat for practical purposes. In France, for telegraphic purposes, a galvanised iron wire, four millimètres in diameter (between No. 8 and No. 9 B. W. gauge) and one kilomètre in length, being the ordinary telegraph conductor, has been generally adopted, and is considered sufficiently accurate and most convenient for the purpose. In England, one mile of pure copper wire, No. 16 gauge, at a temperature of 60° Fahr., has been hitherto the standard in most general use, and it has been adopted in this paper. It is very nearly equivalent to a mile of No. 8 galvanised iron wire, the ordinary conductor for aerial lines in England (the resistance of pure copper being to that of iron as 13 to 90, at a temperature of 60° Fahrenheit, and the sectional areas of No. 16 and No. 8 wires being to one another as 1 to 7·5).

The resistance of copper varies considerably with its temperature, and slight traces of other metals mixed with it increase its resistance in a most remarkable degree; 2 per cent. of arsenic reduces its conducting power to that of iron.

Pure copper is not now generally considered to be the best metal for a standard of resistance, because it oxydises easily, and its resistance varies rapidly with alterations of temperature. Various alloys appear more suitable. German silver is considered one of the best. And an alloy of two parts by weight of gold, and one ditto silver, is proposed by Dr. Mathieson. Mr. Varley has used No. 16 iron wire boiled in oil and enclosed in cement; but no absolute unit of resistance has yet been adopted universally.

Copper, being the best conductor of electricity of any of the metals except silver, was used for the conducting-wire in all the earlier telegraphs; and for submarine or subterranean lines it is undoubtedly the most suitable metal.

It however becomes brittle and loses its tenacity when employed as a conductor for currents of electricity for any length of time. Exposure to the atmosphere, and to changes of temperature, produce similar effects; and its value makes it too tempting a bait to marauders when suspended on poles. Iron wire has, therefore, now entirely superseded copper for conducting-wires suspended in the air, both on account of its superior strength, and also on the score of economy.

Overground Wires.

In long circuits it is advantageous to use iron wire of No. 8 gauge, or even larger, in order to reduce as far as possible the resistance offered to the passage of the current of electricity. To investigate the question of the size of conducting-wire suitable to a particular case, it must be borne in mind that the coils of a needle instrument offer a resistance equivalent to from 12 to 25 miles of No. 16 copper wire, and those of a Morse instrument of from 50 to 200 miles, so that with two needle instruments in circuit, from 25 to 50 miles of resistance are due to the instruments alone; and if the instruments are 10 miles apart, the substitution of No. 16 iron wire for No. 8 iron wire will increase the resistance by only 65 miles of standard resistance; but if the stations are 100 miles apart, the use of No. 16 wire in place of No. 8 wire, would add 650 miles of standard resistance, and the number of elements required to work the line would be too large for practice.

Let us examine the question by means of the equation $Q = \frac{T}{L + w}$. We know from experiment that to work one of the needle instruments used at the Royal Engineer's Establishment with a strong and rapid beat, three elements of the modified Daniel's battery are necessary. The liquid resistance of one of the elements of this battery has been found to be equal to about a mile of standard wire, and the resistance of the coils of the instruments is equivalent to about 20 miles. The force required to be circulated may therefore be expressed by $Q = \frac{3\,T}{3\,L + w} = \frac{3\,T}{23}$. If, now, we insert various wire resistances in this equation, we must increase the number of elements to maintain the same value for Q. Let x be the number of elements required, and we have, with 10 miles No. 8 wire and two instruments in circuit,

$$Q = \frac{3\,T}{23} = \frac{x\,T}{x\,L + 10 + 40}$$

$$= \frac{x\,T}{x + 50}$$

$$\therefore 3\,x + 150 = 23\,x$$

$20\,x = 150$ and $x = 7 \cdot 5$, the number of elements required.

With 10 miles No. 16 wire (= 75 No. 8) and two instruments in circuit—

$$Q = \frac{3\,T}{23} = \frac{x\,T}{x\,L + 75 + 40}$$

$$= \frac{x\,T}{x + 115}$$

$$3\,x + 345 = 23\,x$$

and $x = 18$ nearly, the number of elements required.

With 100 miles No. 8 wire and two instruments—

$$Q = \frac{3T}{23} = \frac{x\,T}{x\,L + 100 + 40},$$ whence $x = 21$, the number of elements required.

With 100 miles No. 16 wire (= 750 miles No. 8) and two instruments—

$$Q = \frac{3T}{23} = \frac{x\,T}{x\,L + 750 + 40},$$ whence $x = 118$, the number of elements required.

These calculations must not be taken as more than approximations to the truth, so much depends upon the degree of perfection of insulation, that it is impossible to make exact calculations on the subject; practical experiments can only *decide* the battery power requisite for the working of a telegraph line. Nevertheless the above considerations are correct in principle, and should govern both the selection of the telegraph wire for particular cases, and the number of batteries estimated for as probably necessary to work any projected line of telegraph. As a rough approximation, Mr. Latimer Clarke states that in dry weather, with a well-insulated line of No. 8 iron wire suspended in the air, one element of Daniel's battery to every four miles of line may be taken as a fair average, and that this number must be doubled under the unfavourable circumstances of wet weather, imperfect insulation, and old batteries. In this calculation, each needle instrument may be taken as representing only five miles of line wire, owing to the more perfect insulation of the fine wire in the coils.

But there is a practical limit to direct telegraphy on overground wires which varies from 300 to 400 miles with No. 8 iron wire. This is owing to the increased tension (obtained by adding batteries in series) required to overcome increased wire resistance. As the electrical tension increases, so does the difficulty of sufficient insulation, and the leakage becomes so great at last that the current circulated is too weak to work the instruments. Other causes also combine to produce the same result, which will be alluded to hereafter.

It will be seen, then, that the gauge of wire to be used as a conductor, should depend in some degree on the length of circuit, but irrespective of any electrical requirements, it is found that No. 8 iron wire possesses a strength and durability which makes it well suited for general purposes of telegraphy, and its weight 387lbs., or about $3\frac{1}{2}$ cwt. per mile, is not excessive.

For military field telegraphs, when an air wire is used, a lighter wire will generally be preferable, and a conductor composed of seven-strand No. 22 galvanised charcoal iron wire, which weighs about 96lbs. per mile, and which has been extensively employed for the *over-house* telegraph lines in our large cities, would be very convenient in some cases. No. 16 iron wire would be lighter, but the seven-strand conductor is more convenient, being more flexible and stronger, and offering a larger sectional area for the conduction of the electric current. For military field telegraphs, however, an insulated conductor, not requiring supports, and yet sufficiently protected by an outer sheathing to be secure from mechanical injury by wheels or horses' hoofs, is much to be preferred. This will be described under the head of Subterranean Conductors.

The seven-strand wire may be used for spans up to a quarter of a mile; beyond this

span annealed iron wire, unless of very superior quality, will not answer; it stretches considerably when strained sufficiently tight, and is liable to break, especially when contracted during severe frosts and when acted on by the force of strong winds, &c.; but both unannealed iron wire, and steel wire, have been successfully used up to spans of 2000 yards, and No. 16 gauge is generally employed for such long spans, being light and manageable, and yet sufficiently strong.

Connections.

In a long line of electric telegraph there must be a great number of connections between the different lengths of conducting-wire, and if these joints are imperfect as regards electrical conduction, the resistance to the passage of the electric currents is very materially increased; if they are not strong, there is danger of the line breaking during frosts or high winds. It becomes, therefore, very important to secure strong joints and a perfect uniformity of conductive capacity throughout the wire.

The most perfect joint in the ordinary No. 8 wire is, perhaps, that which is employed generally in England (fig. 9); it is performed by laying the two extremities side by side for two or three inches, binding them round tightly with No. 16 galvanised iron wire, and turning up the ends to prevent them from drawing asunder. The ends are then cut short with a file and broken off, and the binding continued for a few turns beyond the outer single wires; the whole joint is then coated with solder. If the wire be of good quality, the ends may be simply twisted together as shewn in fig. 10; this joint is adopted in America, and in Russia and Prussia, and answers its purpose fully. The possibility of forming a perfect joint in this manner is a very good test of the quality of the wire. A small hand-vice is used to hold the wire at *a*, and an iron lever is used for twisting the ends; the joint is then moistened with sal-ammoniac and plunged into melted solder.

Fig. 9.

Fig. 10.

The seven-strand wire may be joined by twisting the two ends together, binding them with some of the single wire of the strand and soldering them; or the ends may be joined by a simple reef-knot if the wire is good, but this is not so strong a joint.

The joints in the unannealed iron or steel wire for long spans must be made with great care, in the manner shewn in fig. 9.

Sal-ammoniac is generally used as the flux for soldering iron wires; but chloride of zinc is preferred by some engineers.

In specifying the description of iron wire, it is to be remarked that the qualities vary in the following order, the best and most expensive being placed first.

Best Charcoal Galvanised Iron Wire, No. Gauge.

Best Best Best Galvanised Annealed Iron Wire.

Best Best Galvanised Annealed Iron Wire.

Best Galvanised Annealed Iron Wire.

Charcoal wire was generally used until lately, when Best Best Iron came largely into use and has been found to answer the purpose for the line wire quite as well, at a reduction of 20 per cent. in price; but for binding wire, and for the seven-strand wire, the charcoal iron must be used, or sufficient toughness and pliability will not be obtained.

The process of annealing wire lessens its tensile strength considerably, and even by the process of galvanising or coating with zinc, some strength is lost. Nevertheless, the necessary degree of pliability cannot be ensured in English wire without annealing.

The standard of strength for iron wire is very uncertain. The breaking weight of different specimens of No. 8 iron, tried at Chatham, varied from 10 cwt. to $4\frac{1}{2}$ cwt.,

at a joint made, as shewn in fig. 9—by laying the ends side by side and binding them together. If the wire be too soft, the ends bend down straight, and the wires slip through the binding. If the metal be too brittle, the ends cannot be bent up without injuring its structure, and they break off as soon as any strain is applied.

In the accompanying table are given the diameters, weights, and breaking strains of iron wires of different gauges. The breaking strains are furnished by Messrs. Johnson, wire drawers, of Manchester, but, as before stated, wires vary materially in their tensile strength. In specimens not exceeding $\frac{1}{10}$ of an inch in diameter, Mr. Telford found the breaking strains to vary from 35 to 42 tons per square inch of section ('Barlow on Strength of Materials'). Mr. Shaffner, in his work on the 'Electric Telegraph,' gives in detail the results of his experiments on the strengths of various descriptions of iron wire. Their average breaking strains per square inch of section were as follows :—

	Plain.	Galvanised.	Annealed.
American wire	39·5	28·6	
English wire	24·5	19·85	17 about.

The breaking strain of good English wrought iron bars is about 25 tons per square inch of section, and it begins to yield at about 12 tons.

When drawn into wire, iron increases in strength; but assuming that the yielding point when the structure begins to alter ought not to be passed, and that the point will be about half the breaking strain, it will be safe to strain the best iron wire up to 20 tons, and the worst up to 8 tons per square inch of section.

Number on B. W. gauge.	Diameter in inches.		Weight in lbs. per 100 yards.	Breaking strain in lbs.	Number on B. W. gauge.	Diameter in inches.		Weight in lbs. per 100 yards.	Breaking strain in lbs.
000		·425	149·33		15	$\frac{6}{80}$	·075	4·29	352
00	$\frac{9}{24}$	·375	110·32	9040	16	$\frac{1}{16}$	·0625	3·22	264
0	$\frac{8}{24}$	·340	88·31	7280	17	$\frac{11}{192}$	·0572	2·48	208
1	$\frac{15}{48}$	·3125	68·75	5650	18	$\frac{10}{192}$	·0521	1·91	160
2	$\frac{14}{48}$	·2917	59·90	4930	19	$\frac{9}{192}$	·0468	1·55	128
3	$\frac{13}{48}$	·2708	51·56	4250	20	$\frac{8}{192}$	·0416	1·22	104
4	$\frac{12}{48}$	·25	44·00	3620	21	$\frac{7}{192}$	·0364	·934	79·5
5	$\frac{11}{48}$	·2291	37·00	3040	22	$\frac{10}{320}$	·0312	·687	58·5
6	$\frac{10}{48}$	·2084	30·56	2500	23	$\frac{9}{320}$	·0281		
7	$\frac{9}{48}$	·2075	26·15	2200	24	$\frac{8}{320}$	·025	·473	
8	$\frac{11}{64}$	·1718	22·10	1840	25	$\frac{11}{480}$	·0229		
9	$\frac{10}{64}$	·1562	18·36	1560	26	$\frac{10}{480}$	·0208	·321	
10	$\frac{9}{64}$	·1406	14·97	1280	27	$\frac{9}{480}$	·0187		
11	$\frac{8}{64}$	·125	11·95	1000	28	$\frac{8}{480}$	·0166		
12	$\frac{9}{80}$	·1125	9·24	800	29	$\frac{7}{480}$	·0146		
13	$\frac{8}{80}$	·1	7·05	568	30	$\frac{6}{480}$	·0125		
14	$\frac{7}{80}$	·0875	5·50	456	33		·008		
					36		·005		

N.B.—The relation between the diameter and weight of copper wire is expressed by the formula $d = \frac{1}{2}\sqrt{\frac{w}{L}}$, where d = diameter in inches.

L = length in inches.

w = weight in ounces avoirdupois.

whence the weight of 1 yard in lbs. $= 9\ d^2$.

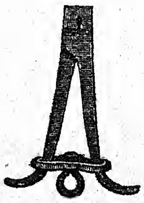
Supports for Overground Wires.—Air wires are generally supported on wooden

posts of sufficient height to keep them out of harm's way, and to allow a free passage beneath them.

This height is usually 20 feet at the poles, a deflection of about $\frac{1}{100}$th of the span, when it does not exceed 100 yards, being allowed in the centre between the points of support. The ordinary distance of the poles from each other is from 70 to 80 yards when a number of wires are suspended from each pole. The strain upon the poles is found to be too great at longer intervals, and it becomes difficult to strain the wires so tight that they may not interfere with one another and produce cross currents, but for a single wire the distance may be advantageously increased to 100 yards; the expense is lessened by this means at the same time that the insulation is improved. Longer spans are admissible occasionally, but they bring a greater strain upon the wire, insulators, and supports than is generally advisable, and a greater deflection between the supports becomes necessary. The supports used in England now, and which experience has proved to be the most durable, are larch poles, from 25 to 30 feet long, 8 to 10 inches diameter at the butt, and 5 to 6 inches at the point, barked, and the knots planed smooth. The butts for 5 to 6 feet in height are charred, and soaked in gas tar, and the tops are usually protected by earthenware caps. They are sunk 4 to 5 feet in the ground. In France, the poles are generally injected with a weak solution of sulphate of copper, which preserves them from decay very much, but to what extent exactly has not yet been determined. In laying out a line of Electric Telegraph it is advisable to avoid sharp bends as far as possible, as the strain upon the pole situated at an angle in the line is very considerable. The strain should be divided amongst several poles when practicable, by adopting a curved line. Generally when a side strain is brought upon a pole it should be stayed by iron wire to a picket, but in some cases it is sufficient to give the pole an inclination in the opposite direction.

An excellent organisation for making the holes, erecting the poles, and stretching the wire in a new country has been adopted in America; it is described fully in Shaffner's 'Electric Telegraph,' page 695. The author states, that two gangs of 9 or 10 men each can dig the holes and erect the posts for a line of Electric Telegraph at the rate of 10 miles a day through the back woods of America. Another squad of 13 men with two waggons, a ladder, and the necessary implements, fix the insulators, and stretch the wire at the same rate. The poles are cut and hauled to the spot by other gangs, and when the wires traverse forests, the trees are used for supports as far as possible. In England the line for the Telegraph wire is first decided upon. Railways and ordinary roads have been generally the routes adopted. The poles are distributed at the required intervals; longer poles being used in particular cases for crossing roads, canals, &c.; a party follows digging the holes and erecting the poles. The insulators are then attached, and finally the wire stretched. This last operation is performed by securing one end of the wire to the terminal insulating shackle. It is then placed loosely on the insulators, or the wooden arms carrying them, for about half a mile, when it is drawn tight by means of a light block and tackle, a species of vice called technically "draw tongs" (fig. 11) being used to grip the wires. The wire is then keyed or tied at intervals according to the description of insulators used, and another section proceeded with. A small vice with drum and ratchet attached (fig. 12) is very useful for adjusting the strain upon the wire.

Fig. 11.



A hand-barrow having a skeleton drum on a vertical spindle is used for carrying the wire as it is being put up. The coils of wire being first distributed at intervals

along the line, they are placed on the drum as required, and so unwound and stretched on the poles. This handbarrow is shewn in fig. 13. The upper portion *a* comes off the spindle when the screw nuts, *s s*, are removed, and allows a fresh coil to be placed on the drum.

Fig. 12.

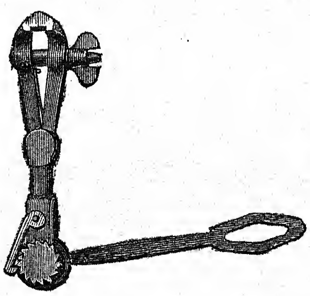
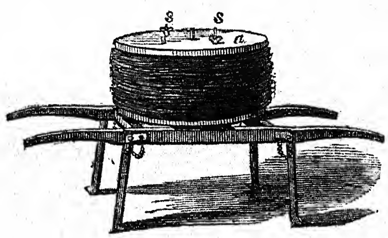


Fig. 13.



Insulators.—In no department of Electric Telegraphy has there been greater variety of practice than in the pattern of insulators used for supporting overground wires. Some of the forms most usual in England at the present day are shewn in figs. 14, 15, 16, 17. Fig. 14 is perhaps the most largely used of any.

Fig. 14.

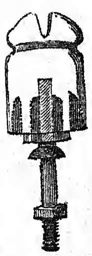


Fig. 15.

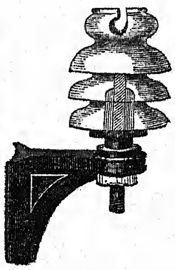


Fig. 16.

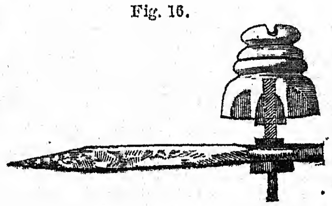
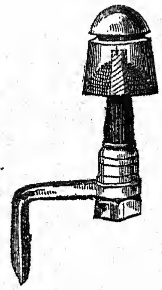


Fig. 17.



The shaded portions shew the double cup shape underneath, which gives it great insulating power in wet weather. The line wire rests in the groove on the top, and is tied by fine wire (No. 18 galvanised iron) at every third support, the tie being performed by twisting the fine wire round the line wire close to the insulator on one side, passing it once round the neck of the insulator, and then twisting the end several times round the wire on the other side. Figs. 15 and 16 are modifications of the same form; (15) is a very perfect insulator, but it is more fragile than (14). The groove at the top is given a form suited to prevent the wire from lifting out. (16) is a very compact and useful form, the wire being passed round the lower ring when it is required as a terminal, or at a bend in the line, the leverage being thus much reduced and sufficient strength obtained for these purposes. These insulators are generally made of white porcelain, which is considered the best substance for the purpose, glass having been found to break during sudden changes of temperature. Fig. 17 is a new insulator, in which the iron work is covered with ebonite, and the insulation is said to be improved thereby; the material is a brown stoneware. The leverage on the iron arm in this insulator is too great for strength.

The iron bolt is secured in its place in all these insulators by a sulphur cement.

No. 14 is adapted for bolting through a wooden cross-arm, as many as 32 insulators being sometimes supported on one pole in this manner. Nos. 15 and 17 are fitted for being nailed or screwed to the poles; and No. 16 for driving into the pole or into trees or walls.

These insulators cost about 1*s.* each.

Fig. 18 shews the usual form of shackle which is employed for making a break in

Fig. 18.

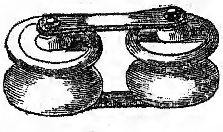
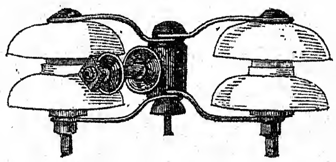


Fig. 19.



the line in order to insert an instrument in the circuit. It is also frequently used for terminating the line.

The most convenient form of terminal insulators is perhaps that shewn in fig. 19; it is Bright's patent, and is largely used in over-house telegraphs in our large towns. One or two insulators are attached to the bolt as may be found necessary; when used as an intermediate support for long spans, or at bends in the line, two insulators are attached as shewn in the figure, and the conductor is completed by soldering a short wire to the line wire at each side.

Fig. 20 shews the insulator generally adopted in France. The iron hook by which the wire is suspended is cemented into the porcelain by a mixture of sulphur and colcothar. It is simple and convenient, but not so perfect an insulator as Nos. 14, 15, 16; the surface between the iron hook and the pole being small, and in the shape of a single wide-mouthed bell, moisture accumulates there more easily than in the forms now adopted in England, and the resistance to the escape of electricity is less.

Fig. 20.

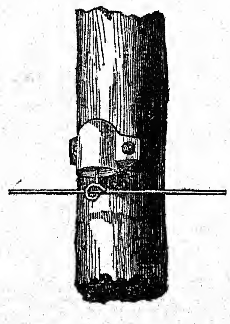


Fig. 21.

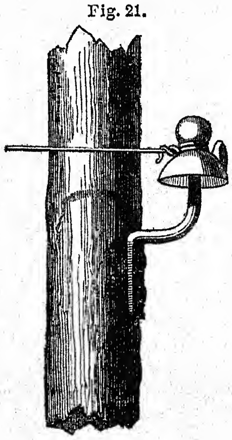
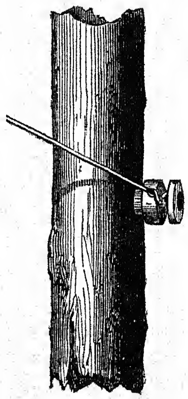


Fig. 22.



For turns and terminals on the French lines, the forms shewn in figs. 21, 22, are used, and permanent tightening ratchets of galvanised iron of the form shewn in fig. 23 are fixed at every mile, the supports being of porcelain.

Messrs. Seimens and Halske have designed a very perfect form of insulator which is used throughout the Russian territory, and also in Prussia, and from its strength and

the perfection of the insulation it affords, it has given complete satisfaction. It is peculiarly suitable for the long lines of telegraph extending across the uninhabited steppes of Russia, where the breaking of an insulator is a serious matter, if it occurs at a distance from a station, involving considerable delay and expense in the repair of the line. Fig. 24 is a view of the insulator, and fig. 25 shews it in section. Fig. 26

Fig. 23

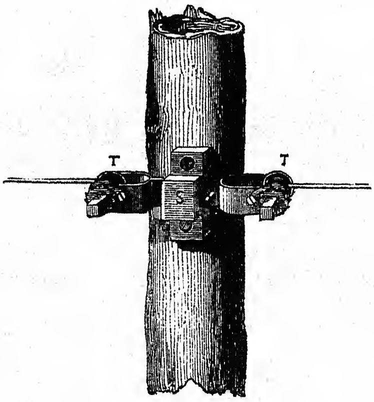


Fig. 24.

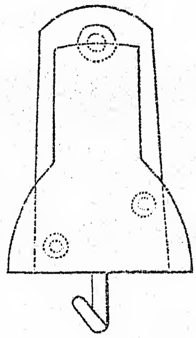


Fig. 25.

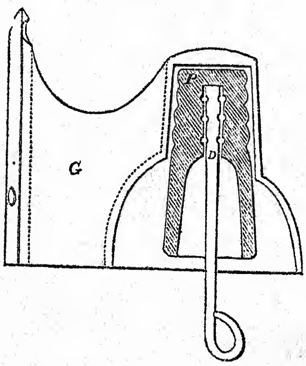
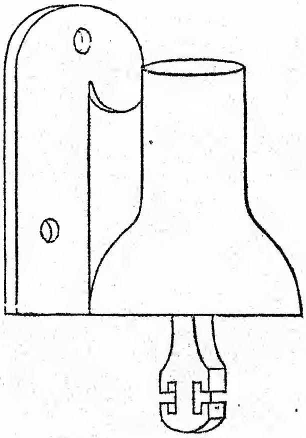


Fig. 26.



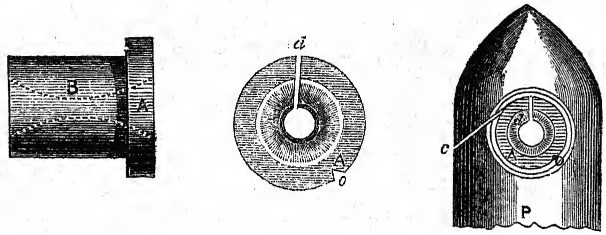
is the "spankoff" or tightening insulator used at every 500 yards. The insulating material is China-ware compressed by machinery which possesses great electrical resistance, it is protected by the outer bell of cast iron which is nailed to the post. A cement of sulphur and colcothar is used to fasten the hook in the insulator and the insulator in the iron bell. The wire is suspended in the iron hook below, which is made of such a shape as to grip the wire slightly. The "spankoff" holds the wire in one of the lower notches, where it is secured by a wedge of iron. A loop is then formed in the wire, and is passed through the other lower notch, and a second wedge secures it from slipping. On the approach of winter, parties are sent along the line of telegraph to slack the wires, in order to allow for the contraction due to

the extreme cold of a northern climate. The loops left at each "spankoff" give a facility for this slacking of the wire.

The insulators cost 1*s.* 3*d.*, and the "spankoffs" 3*s.* 3*d.* each (in England).

In America telegraph lines frequently traverse forests for great distances, and at first the wire was often broken by trees falling across the line. To overcome this difficulty, an open insulator, such as that shown in fig. 27, has been adopted in

Fig. 27.



such cases, which allows the wire to slip freely through it between the tightening posts, situated at about half a mile apart. A falling tree bears the wire down without breaking it, the slack between the neighbouring poles being sufficient to allow for this depression ; and unless the wire be pressed into moist earth, the telegraphic communication is not interrupted. B is a cylinder of glass, having a hole through it, splayed at each end, so that the wire touches only in the centre. A is a flange projecting about a quarter of an inch, and having a notch (*o*) in its circumference ; *d* is the opening through which the wire is introduced. P is the pole, in which an auger hole is first bored of sufficient size and depth to take the flange ; a smaller hole for the insulator is then bored through the post, and a saw-cut (*c*) is made to introduce the wire. The insulator is first placed in the hole so that *d* is opposite to *c* ; the wire is then slipped in, and the insulator is turned until *d* is vertical, when a nail driven in at *o* keeps it firmly in its position.

These insulators are frequently fitted in brackets and nailed to trees.

In India, for the permanent lines, No. 1 galvanised iron wire is used, the supporting posts, of the best timber procurable, being socketed in screw piles 3 feet in length, screwed into the soil. The supports are at 110 yards apart. The insulators are proportionately substantial. For temporary lines, such as were established for military purposes during the late mutiny, the ordinary No. 8 iron wire was used, without insulators, and supported in a very rough manner on branches of trees, &c. During the dry weather the surface of the ground becomes baked so hard and dry that it is a very good insulator, and no difficulty was experienced in working through 200 miles of such a line ; but in the rains these uninsulated lines become almost useless.

CONDUCTORS INSULATED THROUGHOUT THEIR WHOLE LENGTH.

Subterranean Conductors.—The system of underground wires was universally adopted in Prussia when the electric telegraph was first established, and in England such conductors have also been very largely used ; but in almost every case they have now been taken up, and overground wires suspended in the air have been substituted for them.

The reason for this change has been the very great difficulty of preserving the insulation of underground wires unimpaired, and of discovering and repairing faults when they occur.

Faults have generally resulted from the decay of the insulating covering,—occasionally also from mechanical injury, either accidental or wilful. Various substances

have been used for the insulating envelope. At first cotton or silk was wound spirally on the wire, which was then coated with resin and laid in wooden troughs or iron pipes, or the wires were sometimes laid in a matrix of asphalte in trenches cut in the ground. India-rubber was then thought of, and largely used, for covering wires in tunnels and other damp situations: this material was used in combination with cotton and shellac, thin slips of masticated india-rubber being wrapped spirally on the wire, and the overlapping edges united by the use of naphtha as a solvent. The insulation thus obtained was much superior to that which other materials had given; but after a short time the india-rubber began to oxidise, and soon perished, becoming sticky and falling away from the wire. Gutta-percha was then introduced, and although it failed in the same way at first, so that many hundred miles of underground wire had to be taken up, it was found that by covering the wires with tarred tape or yarn over the gutta-percha, and burying them in the ground, enclosed in pipes or troughs, much greater durability was ensured. A system of covering the wire with several independent layers of thin material was also introduced, and the occurrence of air-holes or defects from minute fibres left in the material was thus to a great extent obviated. Notwithstanding all these improvements, however, telegraph engineers are now universally agreed in preferring overground to underground conductors, both on account of their superior cheapness and durability and on account of the much greater facility of repair.

The induction charge in long underground wires has also been found a practical disadvantage, necessitating the employment of electricity of greater tension, and reducing the rate of signalling, as before mentioned. A telegraph engineer of much practical experience states that a mile of No. 16 copper wire insulated with gutta percha and buried underground, offers as much resistance as three miles of equivalent wire suspended on posts in the air.

In many cases, however, it is still desirable to use buried conductors for short distances, and the best systems now known are the following:—

The conducting wire generally used is No. 16 copper, which should be compared with a standard for conductivity, as described under the head of 'Submarine Cables.' The insulating material should be either gutta-percha and Chatterton's compound, in alternate layers, bringing the conductor up to No. 2 gauge, coated externally with Chatterton's compound, and served with tape, as manufactured by the Gutta-Percha Company, or else pure "para" india-rubber in two coatings, protected by an external coating of gutta-percha, and having a further protection of yarn or tape soaked in Stockholm tar, to preserve the insulating material from oxidation as far as possible.* Messrs. Siemens and Halske have patented a system of applying india-rubber to wires without the use of heat or solvents, by bringing the freshly-cut edges into close contact, when a very perfect joint is produced. They apply gutta-percha outside the india-rubber, and then cover the insulated wire by spiral layers of tarred cord, put on under considerable tension to give tensile strength as well as protection; and they use an external armour of Muntz metal, laid on spirally in an opposite direction to the cord, and in strips overlapping one another. Such a conductor is strong, durable, and flexible; and being protected in a great measure from mechanical injury, it seems well adapted for military telegraphs, to be laid on the surface of the ground and across rivers, &c., between points to be temporarily connected by electric telegraph. A cable of this description, weighing 3½ cwt. per mile, having a copper conducting

* An external coating of marine glue has been used lately with great advantage; but owing to the high temperature to which marine glue must be raised before it melts, extreme care is required in applying it over gutta-percha.

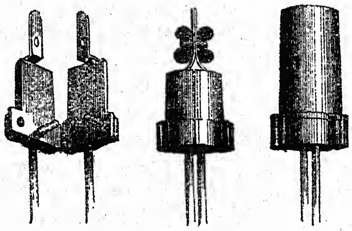
wire of No. 20 gauge, has been subjected to the test of the wheel of a heavy pontoon waggon, with a ribbed tire, passing over it, on a paved surface, and it was not injured otherwise than by being somewhat flattened.

For wires which are to remain underground, a protection by pipes of wood, iron, or earthenware is necessary. The best and simplest mode is perhaps to lay the wire in a groove in flat tiles, which are covered with similar tiles, breaking joints, and set in hydraulic lime mortar. Creosoted wooden troughs have been much used, generally with a galvanised iron lid to preserve them from being destroyed by the blow of a pickaxe.

Iron pipes have also been employed for the same purpose, made in 6-feet lengths and in two halves, with projecting lugs near each end to bolt them together. In streets of towns this is probably the best system, as it gives the greatest security from mechanical injury in taking up and relaying pavement, &c.

Whatever system be adopted, it is necessary that cast iron test-boxes be provided at intervals of about a mile, into which the wires are led and united by means of joints, such as shewn in fig. 28, with gutta-percha insulating caps, to preserve them from contact with the metal.

Fig. 28.

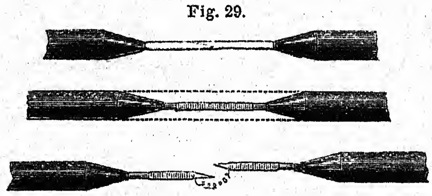


The testing-boxes are very generally made in the shape of mile-posts, with a small door and lock and key, which is a convenient form.

The advantage of these testing-posts will be evident, as they give the means of discovering at once the position of a fault within a mile without difficulty or injury to the wires. The defective mile can then be examined, either by direct electrical tests or, as is more generally done, by cutting the wire half way and testing each half, and repeating this operation until the exact spot is discovered; but without such breaks at intervals, the discovery of a fault would be a very difficult operation, requiring careful and delicate electrical tests, and even then the results would be uncertain.

The joints in underground wires must be made with the greatest care. Fig. 29 shews the manner in which they are effected. The gutta-percha is removed from the ends of the wire for a short distance, and the wire cleaned with sand paper; the ends are then filed to a bevel so as to fit together, when they are spliced together by fine copper wire bound round them. The joint is then heated in a spirit lamp and solder is applied.* The wire and gutta-percha near the joint are then warmed in the spirit lamp, and the gutta-percha tapered over the bare wire until the ends meet; it is again warmed and a strip of thin sheet gutta-percha, about $\frac{3}{8}$ inch wide wound spirally over it, and pressed on till cool. Its surface is again warmed and a second strip wound on in the opposite direction,—and for a very perfect joint a third strip may be advantageously employed; a piece of $\frac{1}{8}$ inch sheet gutta-percha is then applied in the

Fig. 29.



* The Gutta-Percha Company use a second fine wire wound over the first, and soldered only at the ends, to preserve the continuity of the conductor should the joint be separated by a strain. The ends of the wires are sometimes twisted together; but this makes a clumsy joint

same manner, and, when cool, finished off with a warm tool, made for the purpose, working the old and new gutta-percha well together. Moisture, grease, and dirt should be scrupulously avoided, and care should be taken not to burn the gutta-percha. When india-rubber is employed next the wire the insulation at a joint is made good by winding thin strips of india-rubber over the joint, and covering it with sheet gutta-percha in the same manner as before described.

In a commercial point of view it is not considered worth while to bury only one wire, the value of the wire being small compared with the attendant expenses, and the advantage of having a second conductor, in case one should fail, being very great.

"ON THE CONSTRUCTION OF SUBMARINE TELEGRAPH CABLES, EXTRACTED FROM THE REPORT OF THE COMMITTEE ON SUBMARINE TELEGRAPHS.

"1. *The Conducting Wire.*—The conductivity of the metal, other circumstances being the same, does not influence the amount of induction; a bad conductor, therefore, increases the resistance, the induction remaining the same. Hence the conducting wire should be formed of the material which possesses the highest conducting power which can be selected. To ensure this it is desirable in contracts to provide that the conductivity of the wire shall be equal to that of a standard wire at a specified temperature, and then what the wire wants in quality must be made up in quantity at the contractor's expense. It is, however, better to obtain the material with the highest conducting power, because the larger diameter of the inferior conductor would give rise to increased induction. The standard wire should be of some metal or alloy not liable to oxidise, and not subject to rapid variation in conductivity from change of temperature. The metals and alloys we have described in an earlier part of the report appear well adapted to the purpose.*

"The conductor should be formed of a strand of wire, or of some modification of the strand form, so as to prevent the fracture of one of the wires rendering the whole cable useless.

"2. *The Insulating Covering.*—Of the materials which have been submitted to us the best insulator by far is india-rubber. Wray's compound (a mixture of india-rubber, shellac, and silica), and pure gutta-percha, nearly resemble india-rubber in its insulating properties.

"The induction discharge is directly as the length of a wire. The amount of induction discharge from wires of different diameters with coverings of various thicknesses of the same insulating material may be assumed to be, for practical purposes, directly as the square root of the diameter of the wire, and inversely as the square root of the thickness of the insulating envelope.

"Hence by increasing the diameter of the wire and the thickness of insulating covering in the same proportion, the amount of inductive discharge remains the same. The force of the current in a voltaic circuit increases as the square of the diameter of the wire (the length of circuit being constant, and the resistance of the battery being inconsiderable as compared with that of the metallic portion of the circuit), consequently, if it be found inconvenient to increase the conducting wire and the insulating covering proportionately, greater advantage will be obtained by increasing the diameter of the wire than the thickness of insulating covering, for whilst the covering remains the same the induction discharge increases only as the square root of the diameter of the wire, whilst the force of the current increases as the square of the diameter; and if the insulating covering be varied, the conducting wire being constant, the strength of the

* See page 641.

current will remain the same, but the induction will only decrease as the square root of the thickness.

"India-rubber surpasses all other materials in the smallness of the amount of its inductive discharge and the perfection of its insulation. A coating of india-rubber is fully equal to a coating of the gutta-percha, hitherto in use, of double its thickness. Wray's compound and the recently manufactured pure gutta-percha closely resemble india-rubber in both these respects. The mixture of imperfectly conducting materials with gutta-percha has the disadvantage of greatly reducing the insulation and increasing the induction. The interposition of cotton-thread between the wire and an insulating coating considerably increases the induction and diminishes the insulation. The induction is augmented because the cotton-thread, which is a bad insulator, increases the surface of the conductor; and the insulation is impaired, not only because the insulating coating is diminished, by the thickness of the cotton, but probably also in consequence of the great inductive action. The interposition of cotton between two layers of insulating material is equally disadvantageous. The interposition of a viscid insulator between two coatings of insulating material neither decreases the induction nor improves the insulation of the line, but the viscid fluid has a tendency to fill up air holes or flaws in the insulating coatings. Generally speaking the more perfect the insulating property of the material is the less is its inductive capacity.

"India-rubber and Wray's compound are not perceptibly affected by any ordinary increase of temperature, but increase of temperature has a very decided influence in diminishing the insulation of gutta-percha. This substance is, therefore, not well suited for cables to be laid in tropical regions. Temperature affects the induction discharge only in so far as it affects the insulation.

"India-rubber and gutta-percha are subject to deterioration by exposure to the action of oxygen in the presence of solar light; but when light is excluded gutta-percha will remain for months, and india-rubber for a considerable period, unchanged in air, and both will remain unaltered for years in water when light is excluded; indeed, sea water is peculiarly favourable to the preservation of gutta-percha, especially when coated with Stockholm tar. As regards Wray's compound, we have seen a specimen of his No. 2, which it is stated has been exposed to alternations of temperature and exposure during two years, but sufficient time has not elapsed since its introduction to enable us to express a definite opinion as to its durability.

"India-rubber, gutta-percha, Wray's compound, and Chatterton's compound, all absorb water; the absorption is more rapid from pure water than from sea water, and more rapid from sea water than from concentrated brine. The thickness of the material affects the rate of absorption in a peculiar manner. The absorption of water by thick sheets stops short at a limit which is rapidly exceeded by thin sheets; pressure does not appear to increase the amount of absorption; and it does not appear that this absorption is to be feared as a cause of deterioration in submarine cables.

"Pressure greatly improves the insulation, whilst it is being applied, and this effect is more perceptible as the substance is a worse insulator; but it does not appear that pressure exerts any influence on the amount of induction discharge.

"The manner in which gutta-percha can be manipulated and placed on the wire by being forced through a die, renders it less liable to flaws when laid over wire than india-rubber; but india-rubber is generally more free from impurity than ordinary gutta-percha. The more perfect insulation afforded by india-rubber, pure gutta-percha, and Wray's compound, enables flaws to be detected which would pass

unnoticed with ordinary gutta-percha. The occurrence of flaws in the insulating covering of conducting wires can be best guarded against by laying on the material in several coats, and by testing each of the coats under water at a specified temperature. These electrical tests should be continued during the covering, and whilst it is being submerged, in order that comparative results may be obtained throughout.

"3. *The External Protection.*—The form of the outer covering must in each case depend on the local circumstances affecting the site in which the cable is to be laid; and in selecting it, regard should be had to the fact that it is necessary to provide for the repair of the cable everywhere, except in depths which interpose a limit to the possibility of raising it.

"It should be such as to protect the internal core against injuries or strains in laying or in raising for repairs, against the attacks of marine animals, and against abrasion upon a hard bottom; and it must be capable of having joints made in it with ease. It should be such as to give the cable sufficient specific gravity to ensure its sinking evenly. The material by which strength is given to the cable should be effectually protected against corrosion, and should be arranged so as to furnish the required strength with the minimum amount of elongation.

"The suggestion that the materials used in the external covering should not be sufficiently good insulators to prevent the detection of injuries to the internal core during the process of covering, is one which deserves consideration.

"4. *General Conclusion as to Form of Cable.*—The construction of a shallow water cable must, of course, differ from that of a deep sea cable. The shallow water cable will not be much subject to injury in laying from the strain brought upon it, but it will be liable to abrasion and injury from currents, anchors, and other causes, and must, therefore, be constructed with a view of being raised frequently for repairs. For this class of cable the preservation of the outer covering from corrosion is of first importance. The most desirable covering would, if it could be found, be a strong metallic covering not liable to corrode in sea water, rather than iron wire covered with hemp or other material. For cables beyond the reach of anchors, and even of strong currents, it may be necessary to employ iron or steel wire to obtain the necessary strength for raising for repairs, either during laying or after they are laid. In this case the danger from abrasion is less, and the iron or steel wire must be protected from corrosion by means of some outer covering. We think such a covering is to be sought in tarred yarn, protected by some cheap compound of gutta-percha or india-rubber. The wires by which strength is given should be laid longitudinally, or with a very slow turn, and must be kept in place by special binding, or by means of the covering compound. Cables of this general form may also, we believe, be made applicable to the greatest depths which will be met with. In any case the outer covering should be so devised as to prevent a strain coming on the core; and the specific gravity should be adapted to the depth, and be such as to ensure the cable sinking evenly.

"With our present experience, we believe the safest core for a submarine cable is a strand of purest copper wire, in which solidity is obtained by one of the arrangements before mentioned, and coated—according to the locality in which it is employed—with purified gutta-percha or with india-rubber protected by a covering of gutta-percha, and the whole served round with tarred hemp to form a bed for receiving the protecting external wires: each coating of insulating material should be tested in water of a specified temperature to ascertain that its insulation was equal to a specified standard. The size of the conductor and the thickness of the insulating material should be such as to allow of the line being always worked with moderate currents.

A long cable must, however, insulate sufficiently to resist the tension arising from currents termed 'deflections,' or 'earth currents,' which Mr. Varley states have sometimes, in a distance of about 70 miles, a tension of more than 100 cells of Daniel's battery.

"LAYING AND MAINTENANCE OF SUBMARINE CABLES.

"Before the route in which a submarine telegraph cable is to be laid is decided on, a careful and detailed survey of the nature and inequalities of the bottom of the sea should be made, and that line selected where there are fewest probabilities of injuries from mechanical or chemical causes, and where (if possible) the depths are such as to allow of the cable being raised for repairs. In such a survey it is of more consequence to ascertain the relative differences of level of the bottom of the sea at every step than the actual depths ; and it would be of great advantage for this purpose if some instrument could be devised which would enable the actual outline of the bottom of the sea to be traced. The actual position in which a cable is laid should be defined with the greatest precision attainable, to facilitate future repairs.

"*Apparatus for Laying Submarine Cables.*—The failures which have occurred in laying submarine cables are mainly attributable to the employment of ships which have not been constructed for the purpose, and of defective paying-out apparatus. This latter must depend so entirely upon the form of cable to be used, and the depths in which it is to be laid, that it must be left to the engineer to devise in each case. In depths where repairs are possible, the amount of slack paid out should be sufficient to enable the cable to be raised without injury for repairs.

"The question of the ships to be used is one of great importance, to which sufficient attention has never yet been paid. The ship should be of large capacity, to admit of the cable being coiled easily without injury, and great care should be taken to isolate the hold from the engine-room ; it should be of a form to allow of the cable being paid out without any material alteration in the trim of the ship taking place ; it should have sufficient power to enable it to maintain a speed of from 4 to 6 knots per hour in the direction in which it is proceeding, in any weather ; and it should be very steady in a rough sea. These qualities point to the necessity of special ships being built for the purpose. There are difficulties in the way of this being done by contractors for laying cables, because they cannot afford to have ships idle on their hands, and they consequently either hire a ship or build one to serve afterwards for other purposes. But we believe that a ship of the construction we have shown to be necessary for laying a cable would, when not employed in laying cables, be found extremely useful for the ordinary purposes of commerce."

Instruments.

The electric telegraph instruments now in use, although very various in the details of their construction, all depend upon the three following electrical phenomena for their efficient working :—

1. The deflection of a magnetised steel bar, which is free to move on an axis when a current of electricity passes through a conductor in close proximity to it ; the direction of the deflection being dependent upon the direction of the current and the position of the conductor with reference to the magnet, and the effect being greatly increased by causing the conductor to pass many times round the magnet through the coils of an insulated wire. These phenomena are made use of in nearly all the varieties of the needle telegraph and the galvanometer.

2. The magnetic properties temporarily communicated to soft iron by the passage of a current of electricity through an insulated conductor coiled round it, the instant loss of its magnetism more or less completely on the cessation of the electric current, and

the reversal of its magnetic poles on reversing the direction of the current of electricity.

The electro-magnet is employed in some varieties of the needle telegraph and in nearly all other forms of electric telegraph.

3. The chemical decomposition of certain solutions when traversed by a current of electricity. This effect of electrical action is used in some of the printing telegraphs.

The needle telegraph, being the simplest and also that which has been hitherto adopted for military purposes, merits our first attention.

The receiving part of the instrument is similar to a galvanometer—an instrument which is of the greatest use in electrical researches. Galvanometers are of various constructions according to the purposes for which they are intended, but the principle is identical in all. A magnetised needle, or bar of steel, is suspended on an axle in the centre of a coil of insulated wire, through which the current of electricity passes and reveals its presence, its direction, and its quantity by deflecting the needle to the right or left with more or less force. When the effects of currents of great quantity but small tension are to be observed, a few turns of a thick wire are used, offering but slight resistance to the current, nearly the whole force of which is therefore circulated. If the current be weak in both quantity and tension, the same description of wire coil is used, but the needle is suspended horizontally by a fibre of unspun silk, and the force of terrestrial magnetism is overcome by using a second needle of equal magnetic force, fixed on the same axis above the other, and pointing in an opposite direction. A galvanometer so arranged is nearly astatic, and is exceedingly delicate, the current in the upper portion of the coil acting on the lower face of the upper needle, and producing the same effect as the double current on the lower needle. For currents of considerable tension, and but small quantity, such as practically arrive at a telegraph station after having passed through long conducting wires and having suffered much loss from defective insulation, a great number of convolutions of a fine wire are employed, the resistance of the coil used being directly as the tension, and inversely as the quantity of the currents of electricity in circulation.

In the form of galvanometer generally used for telegraphic purposes, the indicating needle is vertical, and outside the coils, and is fixed on the same axis as the magnet, inside the coils, which is influenced by the current. The indicating needle is itself magnetised in the opposite direction to the latter, in order to increase the sensitiveness of the instrument; and this arrangement is generally adopted in the receiving parts of needle telegraphs.

The motion of the needle in telegraph instruments is confined within narrow limits by means of stops, in order that the beats to the right and left, by means of which the letters of the alphabet are signalled, may be clear and distinct; but in galvanometers the needle is allowed to move freely over 90° on each side of the zero point, and the egrees are marked on the dial of the instrument.

Sometimes instruments are arranged with moveable stops, so that they can be used either as galvanometers or as telegraph instruments. Such an instrument is shown n figs. 30, 31.* This arrangement is very convenient for a portable instrument to be used in the repair of a telegraphic line, but is not well suited for general purposes, as the galvanometer needle, to be sufficiently delicate, must be made to move more lightly on its axis than is found to be compatible with the dead beat free from oscillations required for a telegraph instrument.

* The instrument coils I I are so arranged that the magnet can be reached through the space left between them, and re-magnetised without removing any part of the apparatus. The stops *p p* can be drawn back, by means of the screw *o*, when the instrument is to be used as a galvanometer.

The quantity of electricity in circulation cannot be measured directly by the amount of deflection of the needle of the ordinary galvanometer, but by special arrangements,

Fig. 30.

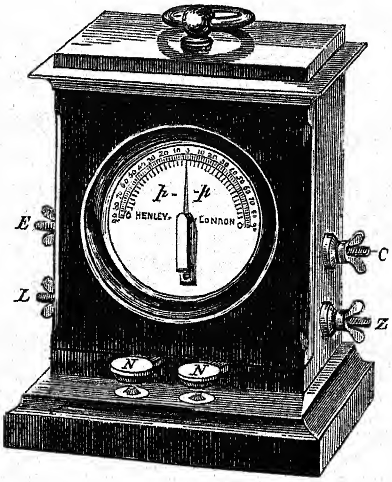
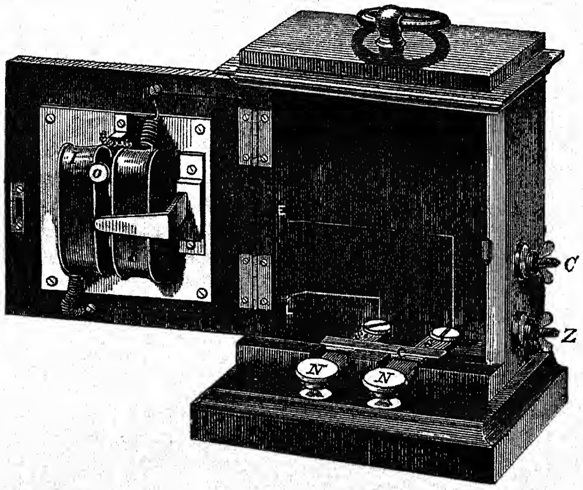


Fig. 31.



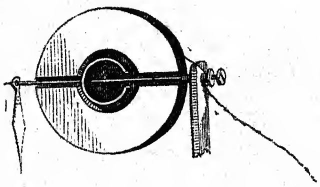
explained in the appendix, the quantity of electricity can be compared directly with the sines of the angles of deflection in one form of galvanometer, and with the tangents of those angles in another form. The ordinary galvanometer, however, although it is not a perfect instrument, serves to indicate the existence and direction of the electric current, and, approximately, its force, and is in most general use. If a thick wire is wound on the coils, the instrument is suited to the measurement of *quantity* currents,

and is termed a "quantity galvanometer." If a great length of thin wire be used, it is termed an "intensity galvanometer."

The coils of a needle telegraph are generally formed of No. 36 copper wire insulated with silk or cotton, and of such a length as to offer a resistance equivalent to from 14 to 25 miles of the standard copper wire.

The shape of the magnetised needle in a telegraph instrument is of some importance, and much attention has been devoted to this point, the object being to obtain the form which shall be acted on most powerfully by the current, which shall give a "dead beat" when deflected by the current and allowed to return to its point of rest, without continuing to oscillate, and which shall retain its magnetism most strongly even when subjected to the influence of powerful currents of natural electricity. The form which appears to combine these advantages in the highest degree is that proposed by Mr. Highton, and adopted by the Magnetic Telegraph Company. It is in the form of a horse-shoe fixed on a horizontal axis in the centre of a circular coil, as shewn in fig. 32. The coil is made in two halves, one of which is taken off in the figure to shew the magnet with its axle and stops. The dial is also removed to shew the index needle, which in this case is of ivory, hanging downwards, and shewn on a black dial. The eye can follow the motions of this needle, without fatigue, more readily than those of a black needle on a light green dial, which is the more usual plan.

Fig. 32.



The stops which limit the motion of Highton's needle are screws passing through the brass frame of the coil, and acting directly upon the edges of the horse-shoe magnet. Some advantage is supposed to result from this position, in the avoidance of reflex oscillations.

Mr. Walker, the superintendent of the telegraphs of the South-Eastern Railway Company, prefers having a number of short, highly magnetised needles placed parallel to one another on a disc of ivory, while the more common shape of the magnet is an elongated lozenge. For short circuits this last form answers very well, and being lighter than the horse-shoe magnet, it is moved by weak currents more sharply, and therefore does not need so many convolutions of fine wire in the multiplier. For long circuits, however, the horse-shoe form is preferred, as it is not found to be such a victim to "deflections" from currents of terrestrial electricity.

During the prevalence of aurora borealis, and at other times occasionally, powerful currents of natural electricity traverse the conducting wires, and permanently deflect the needles of the instruments to the right or left for some time. A slight inequality in the axle or its bearings, or in the balancing of the needle, sometimes produces the same result. To meet this, the instrument-coils and dials are given an adjusting motion of rotation about an axis corresponding with the axle of the needle, which is thus brought into a central position with regard to the stops, and the signals can be made as distinctly as if no deflection existed, unless the disturbing force be most unusually powerful.

The manipulating keys of needle instruments have been made in different ways, but the simplest form is Henley's key, which has been adopted in the military instruments, as shewn in figs. 30, 31.

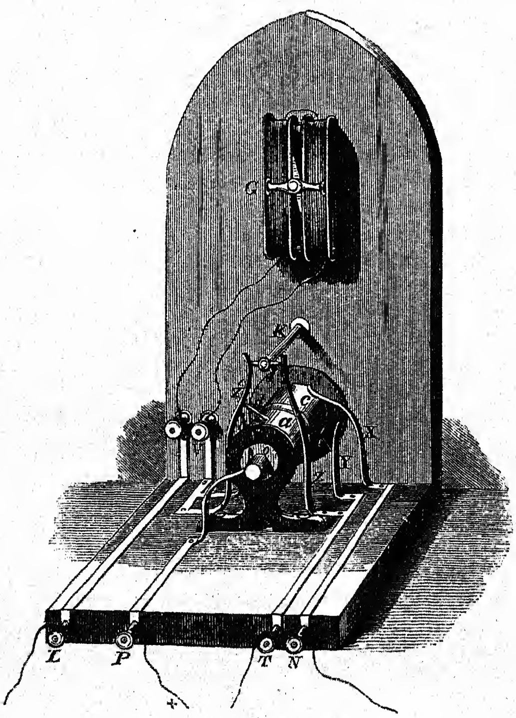
The two springs $s\,s'$ are screwed to a block, in such a manner that when at rest they press upwards against the metal cross-piece c. To insure good contact with this

metal, a steel point with many edges is brazed to the top of each spring, which presses it upwards into a cup in the cross-piece C. The springs are terminated at N N with finger-keys of ivory or ebony, or some other non-conducting substance. Underneath the springs are two metal points, against which they can be pressed down by the finger, and which are in metallic connection with the zinc pole of the battery; C is in connection with the copper pole; *s* is in connection with the earth, *s'* with the line wire through the galvanometer coils.

A current coming from the distant station traverses the coils of the receiving instrument, deflecting its needle, passes from *s'* through C to *s*, and so to the earth.

When *s* is pressed down, the zinc pole of the battery is connected with the earth, while the copper pole remains in connection through C and *s'* with the galvanometer of the sending instrument, and through it with the line wire, and a positive current is instantly sent through the coils of all the instruments in the circuit, and so to the earth at the most distant station. A reverse current is produced by pressing down the key *s'*, and thus the needles of the sending and receiving instruments are simultaneously deflected to the right or left at pleasure.

Fig. 33.

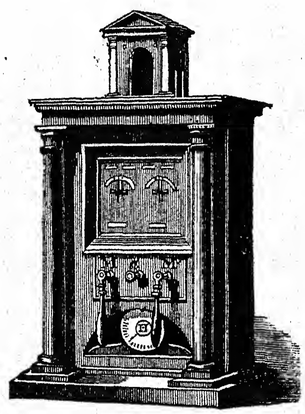


The more usual form of manipulating apparatus, and which is necessarily adopted in the double needle instrument, is shown in fig. 33.

The brass cylinder, *a c*, is divided into two portions, insulated from one another by

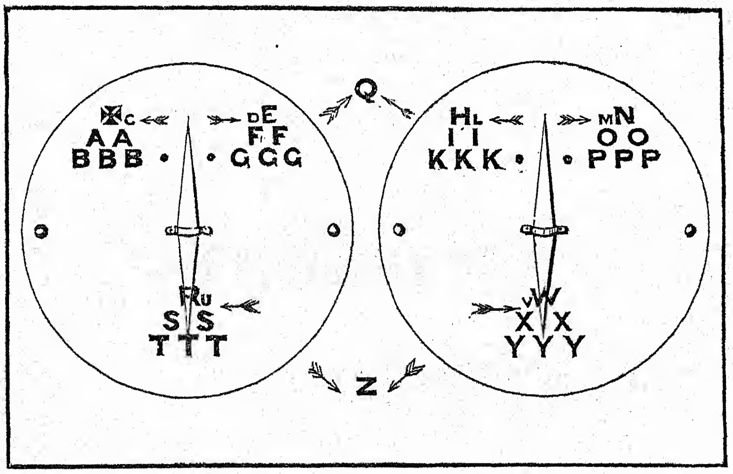
a circle of ivory in the middle; a steel arm *d* is fixed to the upper surface of *a*, and a corresponding arm *e* to the lower surface of *c*, ; *d* is in metallic connection with the positive pole of the battery through *a*, the axis *o*, the spring X′ and the metal connection to the binding screw P. *e* is similarly in connection with the negative pole through X and N. The two springs Y and Z are in connection with the binding screw T, to which is attached the earth wire, and the two corresponding springs on the other side, Z′ Y′, are in connection with one extremity of the wire of the galvanometer coil, and through it with the binding screw L to which the line wire is attached. When at rest the two springs Z Z′ butt against the metallic points at *f*; a current of electricity arriving at L from a distant station can then traverse the coils of the galvanometer, deflecting its needle, pass from Z′ to Z through the points at *f*, and so to T and to the earth.

Fig. 34.



A handle is fixed to the other extremity of the axis of the cylinder *a c*, by means of which it can be rotated to the right or left. When turned, as shown in the figure, the arm *d* presses against the spring Z′, forcing it away from *f* and making a metallic connection between the positive pole of the battery and the instrument coil, and through it with the line wire and the distant instrument, at the same instant the arm *e* presses against the spring Y, thus connecting the negative pole of the battery with the earth; a positive current thus is sent through the instruments in circuit, and the needles are deflected accordingly; a

Fig. 35.



partial rotation of the cylinder *a c*, in the opposite direction, reverses the connections and sends a negative current on the line, producing a deflection of the needles in the opposite direction.

The manipulating handles are shewn in fig. 34, which gives a front view of a double

needle instrument. This arrangement of key is very perfect, but is more complicated than Henley's, and therefore not so well suited for military telegraphs.

The double needle instrument is merely a combination of two single needle instruments. It requires two line wires instead of one; but the increased number of distinct signals which can be made with the two needles enables a despatch to be transmitted more quickly than with the single needle instrument, and it is adopted on most of the railways in England. The ordinary rate of signalling is from 16 to 18 words in a minute, and as many as 25 or even 30 words have been read in special cases. In case of injury to one wire the other is available, and the instruments can be worked as single needles. The second wire is also very useful during magnetic storms, the deflections of the needle being obviated by using the second wire for the return current instead of the earth. The alphabet used with the double needle instrument will be understood from fig. 35, which represents the face of the instrument with its two needles. The letters A to G are made with the left-hand needle; thus, A = two beats of the upper part of the needle to the left, E = one beat to the right, G = three to the right, C = one to the right followed by one to the left, D the reverse of C. H to P are signalled in a similar manner by the right-hand needle. The letters on the lower parts of the dials are made by moving both needles at once; thus for S the needles are simultaneously deflected twice to the right (their lower extremities pointing towards the letter), for Y the lower extremities of both needles are deflected three times to the right, Q is represented by the two upper extremities being deflected inwards, Z by the reversed position of the needles.

A special alphabet was formerly used with the single needle instrument, but the European Morse Alphabet has lately been adapted to it, by using the beat of the needle to the left to represent a *dot* and the beat to the right to represent a *dash*. This simplification is an important advantage.

THE EUROPEAN MORSE TELEGRAPH ALPHABET AND SIGNALS.

ALPHABET.

Magnetic, or Printing.		Single Needle.	Magnetic, or Printing.		Single Needle.	Magnetic, or Printing.		Single Needle.
A	. —	\/	J	. — — —	\///	S	. . .	\\\
ä (æ)	. — . —	\/\/	K	— . —	/\/	T	—	/
B	— . . .	/\\\	L	. — . .	\/\\	U	. . —	\\/
C	— . — .	/\/\	M	— —	//	ü (ue)	. . — —	\\//
D	— . .	/\\	N	— .	/\	V	. . . —	\\\/
E	.	\	O	— — —	///	W	. — —	\//
F	. . — .	\\/\	ö (œ)	— — — .	///\	X	— . . —	/\\/
G	— — .	//\	P	. — — .	\//\	Y	— . — —	/\//
H	. . . .	\\\\	Q	— — . —	//\/	Z	— — . .	//\\
I	. .	\\	R	. — .	\/\	Ch*	— — — —	////

French accented é . . — . . (\\/\\)

* N.B.—Ch must always be sent — — — — and never as separate letters.

ADDITIONAL SIGNALS.

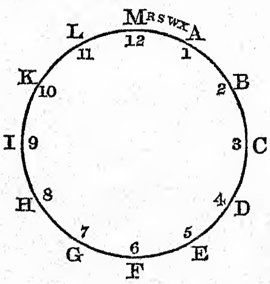
	Magnetic, or Printing.	Single Needle.
T Understood	—	/
I or E Not understood . . .	- -	\
Comma	- {For printing. - — - — - —}	\
S Q Full stop (.)	- - - — — - —	\\\//√
M Q Wait	— — — — - —	// //√
G Q Fresh paragraph . . .	— — - — — - —	/\\//√
P P Parenthesis ( ) . . .	- — — - - — — -	√/\\ √/\\
C C Inverted commas (" ") . .	— - — - — - — -	/\\/\\ /\\/\\
L L *Underlined* . . .	- — - - - — - -	√\\\ √\\\
D Q End of address . . .	— - - — — - —	/\\\//√
M M Instructions after message .	— — — —	// //
P Q End of message . . .	- — — - — — - —	√/\\//√
Correction (in sending) . .	- - - - - - - -	√√√√√√
R R All right	- — - - — -	√\\ √\\
Repeat, or ? . . .	- - — — - -	\\//\\\

SIGNALS FOR NUMBERS.

Magnetic, or Printing.	Single Needle.	Magnetic, or Printing.	Single Needle.
1 - — — — —	√///	6 — - - - -	/\\\\\
2 - - — — —	\\√//	7 — — - - -	//\\\\
3 - - - — —	\\\√/	8 — — — - -	///\\\
4 - - - - —	\\\\√	9 — — — — -	////\\
5 - - - - -	\\\\\	0 — — — — —	/////

In telegraphing *numbers* on the needle instruments, give the signal F I before the figures and I F after them, sending each figure in succession.

It will be observed that Morse's alphabet is applied to the ordinary single needle instrument by using the beat to the right (/) for the dash (—), and the beat to the left (\) for the dot (-). In using the magnetic single needle instrument, or the printing instrument, the difference between *dots* and *dashes* must be made by *time*, but in using the ordinary voltaic single needle instrument the beats to the right or left may be made at an uniform rate, and as quickly as the eye can follow them accurately, a momentary pause being made after each letter.

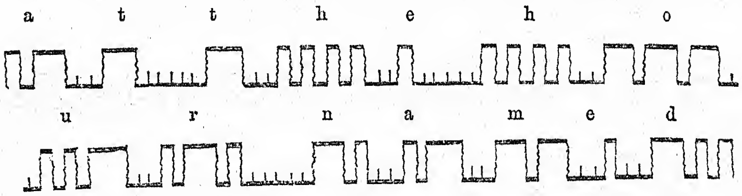


CODE TIME.

Hours.		Min.		
7	......	0	would be sent	G
3	......	15	,, ,,	C C
11	......	59	,, ,,	L L X
12	......	12	,, ,,	M B S

Rules for Spacing. The length of a dot being taken as the unit.—1. A dash is equal in length to 3 dots. 2. The space between the elements of a letter is equal to 1 dot. 3. The space between two letters of a word is equal to 3 dots. 4. The space between two following words is equal to 6 dots.

The above rules are illustrated by the words below, "at the hour named"—



In sending through long circuits, especially if submarine or subterranean, the dots must be made firmly and distinctly, thus, - - - -, and not thus, ...

When several stations are connected by electric telegraph, each station should have a distinct "call signal," such as *D S*, *N C*, &c. The prefixes *S A*, and *Z A*, are also used to denote that the message is *on service*, or *private*.

In sending a message from one station to another, the following system should invariably be followed :—

1. Give the call signal of the station to which you are sending.
2. When you have received the answer, send your own call signal.
3. When you have received the answer, send the proper prefix, then the code time, and then the number of words in the message about to be sent, including the addresses, but not including "from" and "to," which words are printed on the form.
4. Send the addresses of the persons from and to whom the message is sent, and give the signal D Q.
5. Send the message.
6. If necessary, give the signal M M, followed by instructions how the message is to be forwarded.
7. Signal P Q, signifying the message is completed.
8. If the number of words sent back by the receiving station is not correct, send the right number again, and then send the initial letter of each word of the address and message until the mistake is discovered.

In receiving a message—

1. On receiving your call signal, send back the same to signify you are at your post.
2. On receiving the call signal of the sending station, send back the same, signifying you understand.
3. Receive the message, giving the "understood" or "not understood" at the end of each word.
4. Count the number of words you have received (as above).
5. If there is an error, send "?" and the number of words you have received. You will receive the correct number again, and then the initial letter of each word, which must be repeated back until the error is discovered.

The great advantage of the single needle instrument is its simplicity; it is the simplest and most portable form of telegraph, and so efficient, that the Magnetic Telegraph Company still employ it on their busiest lines. As many as 20 words in a minute can be transmitted and read by expert operators; from 12 to 14 words is however the ordinary rate.

In needle telegraphs, the person sending a despatch sees the working of his own

needle, which assists him in sending correctly, and he is always in direct communication with the distant station without the necessity of putting clock-work in motion, or any danger of the two instruments not being in adjustment together, as in the printing or letter-showing telegraphs.

The instrument coils offering a comparatively feeble resistance, four or five instruments can be put into the same circuit without difficulty, and the same instrument can receive and transmit in either direction.

The disadvantages of needle instruments are that they do not record the messages sent, the strain on the eyesight is considerable, and two persons are required to receive a message quickly, one observing the motions of the needle and dictating the message as it is received to the second, who writes it.

Messrs. Bright have patented a telegraph which is used in combination with single needle instruments on the lines of the British and Irish Magnetic Telegraph Company. Two bells are used, one having a shrill tone and the other a deep tone. These bells are struck by small hammers set in motion by electro-magnets, the shrill tone corresponding with the deflection of the needle to the left, or the dot, and being produced by a current of negative electricity on the line, and the deep tone corresponding with the beat to the right, or the dash, by a current of positive electricity. A practised clerk can receive by ear, with this instrument, as quickly as he can write, and he is always in direct communication with the sender by means of a single needle instrument at the sending station. The bells require, however, a strong current of electricity to produce a distinct sound, and relay magnets and a local battery are necessary, which will be described under the head of the Morse instrument an arrangement of mufflers to deaden the vibrations of the bells is also used, and these complications unfit the instrument for military purposes.

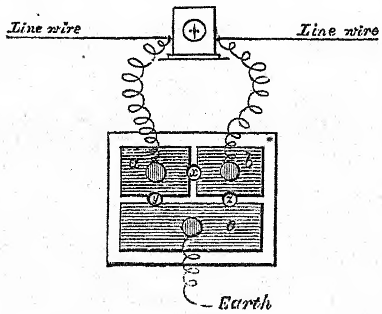
A simple instrument, giving two distinct sounds corresponding with the dot and the dash, and showing also the movements of the needle to the right or left, might probably be constructed, which would materially assist the receiving clerk and enable him, after some practice, to write the message as he received it by sound, and thus save time or a second clerk. Steinheil constructed an instrument which appealed to the senses both of sight and hearing, in the early days of electric telegraphy; but it was never brought into general use, probably on account of its being too complicated.

When several needle instruments are in connection in the same circuit the line wire is cut at each station, and the ends united by an insulating shackle, from each side of which a wire is carried into the office, one being attached to the *earth wire* terminal and the other to the *line wire* terminal of the instrument. Each instrument has its own battery, and is thus always ready to receive or send a message, which will be signalled at every station in the circuit—the currents passing through the whole line and all the instruments from the earth at one extremity to the earth at the other extremity of the line.

When several instruments are thus in circuit, it is often useful to break the continuity of the line at some point so as to form two or more independent circuits; thus if stations A, B, C, and D are all in connection. Each instrument has its battery, but only the two terminal stations have earth wires, the current passing through the instrument coils of the two intermediate stations. If A wishes to communicate with B, the message can be read at C and D also, and the stations C and D cannot communicate until A and B have ceased. Arrangements called "switches" or "commutators" are used to obviate this difficulty—a simple form is shown in fig. 35. Three brass plates *a*, *b*, *c*, are screwed to a piece of varnished mahogany, and holes are bored at *x*, *y*, *z*. Wires are brought from the *earth* terminal and *line wire* terminal of the instrument to binding screws at *a* and *b*, and *c* is connected with the earth: a brass

pin can be inserted in x, y, or z. If placed in x, the current between the other stations will pass from a to b through the brass pin without affecting the instrument in connection with it, and the resistance of its coils will thus be taken out of the line. If placed at y, the instrument is in direct communication with the stations on the right, the currents arriving from that side passing through the instrument to a, and through y to the earth plate c: and if the pin be placed in z, the instrument is in communication with stations on the left in similar manner, the other part of the line being left free for communications between the remaining stations.

Fig. 35.



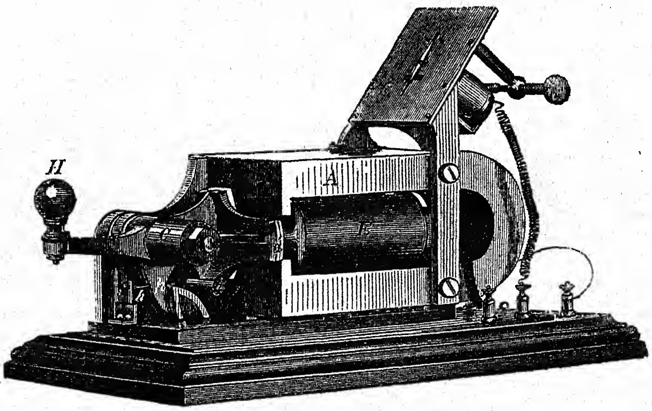
Needle Telegraphs are sometimes made with a horizontal needle, arranged in the manner shown in the sine galvanometer, fig. 53. A permanent magnet must be placed near the needle to bring it to rest at zero. This method is adopted in India and is found convenient, as, by varying the position of the magnet, the disturbing influence of terrestrial currents is counteracted.

Needle Telegraphs have also been constructed in which the deflections to the right and left are obtained by electro-magnets, instead of by the usual arrangement of the galvanometer. This system is recommended by some authors on account of the superior sharpness and distinctness of the *beats* over those produced by the galvanometer arrangement; but it has not come into general use, because it requires more powerful currents of electricity, and either balance springs or reverse currents of electricity must be employed to overcome the residual magnetism of the electro-magnets: moreover, the magnetised needles must be carefully adjusted as to their distance from the armatures; if they touch them they will adhere. The electro-magnet is not employed to advantage when it has to move its armature through any distance, its force decreasing as the square of the distance. In the galvanometer the maximum force is employed to overcome the inertia of the needle and deflect it from its normal position, and the force decreases as the deflection increases. When electro-magnets are employed for the purpose, their minimum force acts at first, and it increases as the needle is deflected and approaches the attracting pole.

Magnetic electricity has been largely employed for needle telegraphs. Mr. Henley manufactures an instrument on this principle, which is shown in fig. 36. A is a permanent magnet, N and S its north and south poles, B is a portion of a hollow brass cylinder, or wheel, on the surface of which are fixed pieces of soft iron, $a\ a'\ a''$, and which is moved through a small arc on the central axis O, by means of the lever and handle H, its motion being limited by the stop D, against which two projections $p\ p'$, padded with india-rubber, strike. B being heavier than H, p' buts against D when the instrument is in its normal state. E is an electro-magnet, its poles being horizontally beside one another, and so placed that $a\ a'\ a''$ pass very close to them, but do not touch them. In the normal position, a is opposite to N, and to the left hand pole of the electro-magnet, communicating to it, by induction, S polarity; a' is opposite to S, and to the right hand pole of the electro-magnet, which thus becomes a N pole; a'' is inactive in this position. When H is depressed, a is removed from its position opposite the left hand pole of the electro-magnet, and is replaced by a'', which communicates to it N polarity, while a', still opposed to the right hand pole of the

electro-magnet, is removed from the influence of S, and brought opposite N, thus reversing the polarity of E. At each reversal of the polarity of E, a momentary cur-

Fig. 36.



rent of induced electricity circulates through its coils, which, being in communication at one extremity with the earth, and at the other with the coils of the electro-magnet of its receptor, and so through the line wire to the distant station, affects both the needles at the same moment. In this instrument the needle is always acted upon by alternating reverse currents of momentary duration, and therefore it is necessary to temper the poles of the electro-magnet of the receptor slightly, in order that they may retain some of the magnetism communicated to them by the momentary currents of induced electricity, and so hold the needle over to the side to which it may have been deflected until the reverse current, destroying the residual magnetism, imparts magnetism of the opposite kind. The deflection to the left is taken as the zero corresponding with the normal position of the lever B H, and the deflections to the right are given different durations to signify the *dots* and *dashes* of the Morse alphabet.

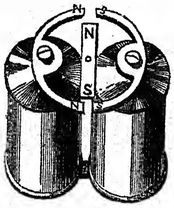
The signals given by this instrument are not so distinct and rapid and easily read as those on the single needle instrument worked by voltaic electricity, the signals representing the *dot* and the *dash* on the latter being deflections to the left or the right, which can be made with uniform rapidity, the zero being the vertical position of the needle. The induced electricity obtained from magnets has also the disadvantage of being developed under considerable tension while it is small in quantity: these conditions require very perfect insulation in the conducting wires.

The degree of tension may be lowered considerably by employing a thicker wire on the electro-magnet. A large pair of magnets, weighing about 50 lbs. each, and having electro-magnets wound with No. 26 wire, gave currents of considerable quantity and of comparatively low tension: the resistance of the coils was about 20 miles. They were constructed to work through 300 miles of over-ground wire. A pair of similar magnets, having their coils wound with No. 40 wire, of such a length as to give a resistance of between 200 and 300 miles, produced a current of much higher tension and much smaller in quantity: the least defect of insulation was sufficient to cut off the communication between these instruments. For example, they worked perfectly through a well insulated cable 105 miles long, between Mahon and Barcelona; but when used in connection with a cable 34 miles long, between Dieppe and Beachy Head

the insulation of which was imperfect, no signals could be transmitted, although weak signals were obtained by the use of 36 cells of Daniel's battery.

The form of the armature of the electro-magnets in the receptors of these instruments is shown in fig. 37. The needle is attracted by two of the extremities of the horns, and repelled by the other two; when the current is reversed in the electro-magnet, the attractions and repulsions take place in the opposite direction.

Fig. 37.



In order to reduce the resistance in the circuit, the coils of the large electro-magnet are excluded when the instrument is in the position for receiving, by the contact between the spud *h* and the spring *f*. *f* is in connection with the earth, and *h*, through the brass framework of the instrument, with the coil of the electro-magnet of the receptor.

Before dismissing the subject of needle telegraphs a brief notice must be made of Professor Thomson's reflecting galvanometer, which was the only instrument by means of which messages could be transmitted through the Atlantic cable during the last days of its life. It consists of a light magnetised steel needle, suspended by unspun silk in the centre of a coil of fine wire; a small mirror is cemented to the middle, and a lamp is placed so that its light may be reflected by the mirror. A very slight movement of the needle causes a considerable movement in the spot of light which is thrown upon a graduated arc of a circle. The needle is brought to its zero by means of a magnet.

This arrangement was found very useful on board ship in laying the Atlantic cable; the needle, being suspended by its centre of gravity, was not affected by the motion of the vessel. And after the faults in the cable had reduced the force of the currents arriving from Newfoundland to so low a degree that no other instrument would give any indication of the signals, this delicate galvanometer continued to work satisfactorily, until the faults increased so far as entirely to cut off the communication through the cable.

Dial Telegraphs.—These instruments are chiefly valuable from their not requiring any special training in the operator, a very little practice enabling any one to send or receive a despatch by their means. They are more complicated and expensive than the needle telegraph, and the same rapidity of transmission cannot be attained with them as with the latter. They have the same disadvantages of not recording their message, and requiring two clerks, one to receive and the other to write. The simplest of these instruments is probably Henley's dial telegraph, shown in fig. 38.

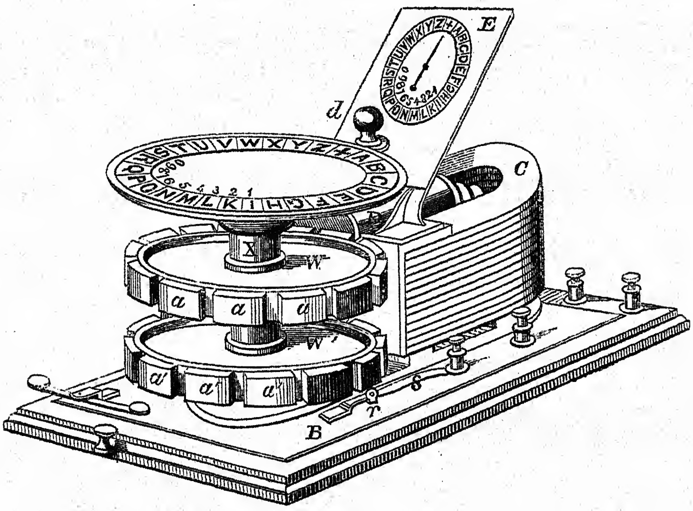
The horizontal dial, carrying the letters, is supported above the base board of the instrument by a vertical rod, which passes through the hollow axis X of the brass wheels W W′. The handle *d* is also attached to X by an arm underneath the dial, so that as the handle is moved round the dial the wheels move with it. C is a compound horse-shoe magnet; its power (depending chiefly on the number of laminæ or plates) is suited to the electrical resistance of the particular circuit through which it is intended to work.

The magnet is generally powerful enough in these instruments to work another instrument at any distance up to 50 miles. D is an electro-magnet, the core being in the form of a horse-shoe, and the poles being vertically above one another, and between the two poles of the permanent magnet. On the circumference of each of the wheels W W′ are secured 13 pieces of soft iron *a*, *a*, *a*,—*a′*, *a′*, *a′*, of such a size, and so placed with respect to one another, that at the moment when *a* is opposite to the north pole of the permanent magnet, *a′* is opposite to the south pole, *a* imparting by induction north polarity to the upper end of the electro-magnet, while *a′* imparts south polarity to the lower end. A reverse action takes place when the

handle has been moved through the 26th part of the circumference of the circle (corresponding with the distance between two letters): at the instant ot each reversal of the pole of the electro-magnet effected in this manner, currents of electricity in alternate directions pass through its coils.

One extremity of the coil wire is connected with the earth, the other with the coils of a small electro-magnet (behind the receiving dial of the instrument), through which each induced current passes, then traverses the line wire to the distant instrument, circulates through the coils of the electro-magnet of its receptor, and so passes to the

Fig. 38.



earth through a short circuit formed by the spring s, and a screw on the metal plate B; these touch each other only when the handle is brought to zero, a roller *r* on the spring passing at that moment into a notch on the under side of the lower wheel, and thus allowing s to rise and come into contact with B. The object of this is to cut out of the circuit the resistance of the coils on the large electro-magnet, which is equal to several miles of the line wire.

The alternating currents of electricity thus circulated through the coils of the electro-magnet of the receptor work an escapement in the following manner:—

Pieces of soft iron are fixed on the poles of the electro-magnet, forked at their ends, and approaching each other very closely; the lower end of a magnetic-needle hangs in the slot so formed, and being always within and surrounded by the soft iron, it is acted upon much more powerfully by the magnetic force than if it simply vibrated between the poles of the electro-magnet. The other end of the needle is formed into two pallets, which, by its alternate movement, act on inclined teeth on the opposite sides of an escapement wheel, the teeth being cut in a peculiar way to prevent recoil.

The small index-hand of the receptor is thus made to revolve in the same manner as the seconds hand of a watch.

It will be evident from this description that the movements of the handle *d*, will be exactly followed by the small index-hand on the receiving dials of both instruments, whatever letter is indicated by the position of *d*, being also pointed out by the index-

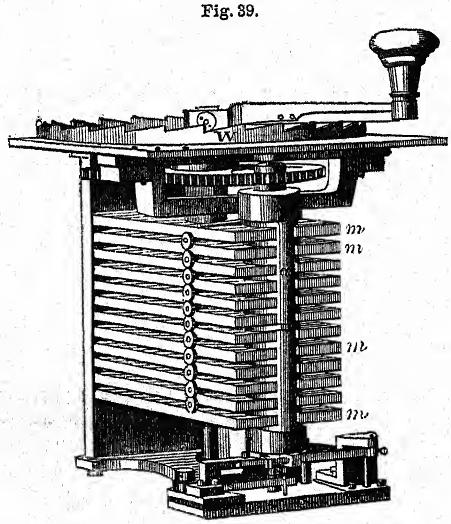
hand of the receptors, and thus messages can be sent and received by any person after a little practice without the knowledge of a special alphabet.

The spring and button on the left of the instrument are for setting the index-hand of the receptor, should it at any time get wrong. On slightly raising the spring the circuit is broken with the coils, so that D can be moved to the same letter on the large dial that the index points to on the dial of the receptor, without any current passing. On pressing the button down, a short circuit is formed between the two outer terminals connected with the line and earth wires, so that the handle D on the large dial and the index of the receiving dial will be moved simultaneously round to zero without affecting the distant instrument.

An instrument very similar in construction, but worked by Voltaic Electricity, is made by the same person, and is preferable in some points of view. The rotation of the dial is more easily effected than in the magnetic instrument, in using which some force is required to overcome the attraction of the magnets: but for short permanent circuits the magnets are generally preferred, because the voltaic batteries give some trouble, and the maintenance of a sufficiently well insulated line for short distances is not difficult.

Messrs. Siemens and Halske have a magnetic dial telegraph, somewhat on the same principle as Henley's. They consider that they obtain greater effect from the same number of plates of permanently magnetised steel by separating them from one another, and allowing each one to act independently, but in the same direction, upon the soft iron armatures of the electro-magnet. In their instrument the electro-magnet is a straight bar of soft iron, wound with insulated wire and placed vertically inside a cylinder (a, fig. 39), which is made to rotate on a vertical axis between the poles of the permanent horse-shoe magnets m, m, m. The cylinder is made of brass, and has two strips of soft iron sunk into its circumference parallel to its axis, and in communication with the poles of the soft iron core of the electro-magnet inside it. Opposite polarities are induced in these strips of soft iron as they come alternately opposite the north and south poles of the permanent magnets, and alternate currents of positive and negative electricity are thus generated and transmitted to the distant station, setting in motion index-hands by an escapement somewhat different in form but similar in principle to Henley's. The serrated wheel, W, enables the operator to stop the handle at any particular letter with greater certainty.

Fig. 39.



These instruments have been largely used in Russia, Germany, Turkey, and Sweden, and have given great satisfaction.

Professor Wheatstone was the first to use a dial telegraph worked by magnetic electricity, and he has lately improved upon his original instrument, which is now a

most beautiful and perfect piece of mechanism, though somewhat complicated in its details. He uses a constant succession of alternating currents produced by rotating armatures, the permanent magnet and electro-magnets being fixtures. A number of metal levers are connected with buttons placed round a dial, and corresponding with the letters of the alphabet and other signs upon it; an index-hand is attached to this dial, which moves round under the influence of the electric current, and points to any letter the button opposite which may be depressed. An "indicator" is attached to each instrument, having a small dial and index-hand. The operator with one hand communicates a rotary motion to the armatures by means of a small winch and handle and multiplying wheel, and with the other presses down in succession the buttons opposite to the letters he wishes to indicate. Whenever a lever is depressed, the index-hands of the "transmittor," and of both the "indicators," are set in motion, and revolve until the letter is reached the lever of which has been depressed, when the currents of electricity are diverted into another channel, and the hands stop and indicate the letter. By the action of depressing any one of the levers, any other lever which may have been depressed before is raised, so that only one lever can be depressed at one time.

The advantage of this system is, that an uniform rate of rotation being preserved, the force of the alternating induced currents is uniform, and there is less liability to error from the escapement failing to move the index-needle, than in the case of the simpler instrument as constructed by Mr. Henley. The force of the induced magneto-electric current depends very much upon the rapidity with which the contact is broken and made; and a hesitation in the movement of the handle of Henley's dial may so reduce the force of the currents, that the needles at the sending and receiving stations may not move synchronously.*

Both systems are, however, coming into use in our large towns for communicating between mercantile firms and warehouses, &c., and appear to give great satisfaction; an alarum bell is generally attached to the instrument, which can be put out of circuit by a switch.

In France, a system of dial telegraphs (Télégraphes à Cadran) has been adopted exclusively on the railways—a very perfect instrument, invented by M. Breguet, and worked by voltaic electricity, being generally used. The mechanism of this instrument is somewhat complicated. The motion of the index-hand is not produced directly by the electric current, but by clockwork, the escapement of which is so arranged with two ratchet wheels and a catch which oscillates between them under the influence of an electro-magnet, that each current of electricity which is transmitted on the line releases a tooth of one of the wheels and catches the succeeding tooth of the second wheel, allowing the index-hand to perform a revolution of $\frac{1}{26}$th of the circumference, or to pass from one letter to the next. The manipulating handle of the transmitting dial is in connection with a wheel, having pieces of metal inserted in it in such a manner as to make and break contact with the battery (or in some cases to reverse the current from the battery) 26 times in the course of one revolution, a separate pulsation being transmitted for each letter or figure on the dial.

When several of these instruments are combined in one circuit, each intermediate station has two alarums and two galvanometers, one for the line on the left and one for that on the right.

In the normal state of a station, *i. e.*, ready to receive a dispatch from either

* Siemens and Halske's instrument appears to hold an intermediate position: more complicated than Henley's, it nevertheless seems less liable to error from unskilful manipulation, owing to the greater distance between the soft iron armatures and the more rapid motion communicated to them by the multiplying wheels.

direction, the alarum and galvanometer on each side are put in communication with the line wire on that side and with the earth by means of two commutators, so that a current arriving from either side rings the bell on that side only.

When one of the bells is rung, the operator turns his commutator so as to throw that bell out of circuit, and the instrument into circuit with the line on that side, and the message is received.

Should the distant station wish to communicate with the station on the other side of that with which it is in direct communication, a signal is transmitted to that effect, which signal is repeated at the receiving station and sent on to the next, and so on from station to station; and each operator, after having done so, turns his commutators so as to throw his alarums and his instrument out of circuit, and to allow of direct communication, the current passing only through his galvanometers.

During the transmission of the dispatch between the distant stations, the needles of the galvanometers are agitated; when they return to rest, the intermediate stations know that the dispatch is finished; they then restore the connections to their normal condition.

This is the system adopted on the French lines of railway, and very generally on the continent of Europe, and which, it will be observed, is more complicated than the system of needle telegraphs used in England.

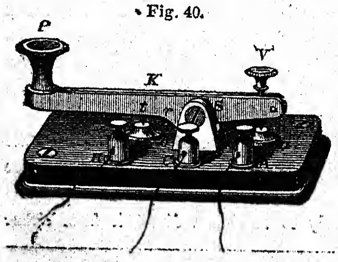
The advantage is that comparatively untrained operators can work the telegraph, but this advantage appears rather problematical, as trustworthy and well-educated persons must always be employed on such duties; and the alphabet and manipulation of the needle telegraph becomes perfectly familiar to an intelligent person of good education in about a month, while its superior simplicity and cheapness, and less liability to get out of repair or out of adjustment, and also the greater rapidity with which messages can be transmitted, appear to justify the preference given to needle telegraphs in England.

PRINTING TELEGRAPHS.

The most simple and most generally used of these is of American origin, invented by Professor Morse, and adopted in America at the same time that Messrs. Cooke and Wheatstone introduced the needle telegraph in England.

The Morse telegraph, slightly modified and improved, is now adopted on almost all the principal telegraph lines in the world. In principle it depends upon the attraction exercised by an electro-magnet on a soft iron armature attached to one arm of a lever, the other arm of the lever carrying a pen, which is brought into contact with a strip of paper every time that the lever is raised. The paper is kept in regular motion by clockwork; and as currents of longer or shorter duration are circulated through the electro-magnet, it attracts the armature in a corresponding manner, and the pen marks lines on the paper of different lengths, separated by spaces when no current is passing. These lines and spaces are combined into letters and words, according to the alphabet given at page 662. The transmission of the currents of electricity is effected by the operator by means of a key, shown in figure 40: K is a brass lever, having at the extremity of the longer arm a button, P, of insulating material, adapted to the finger of the operator, and at the other end a screw

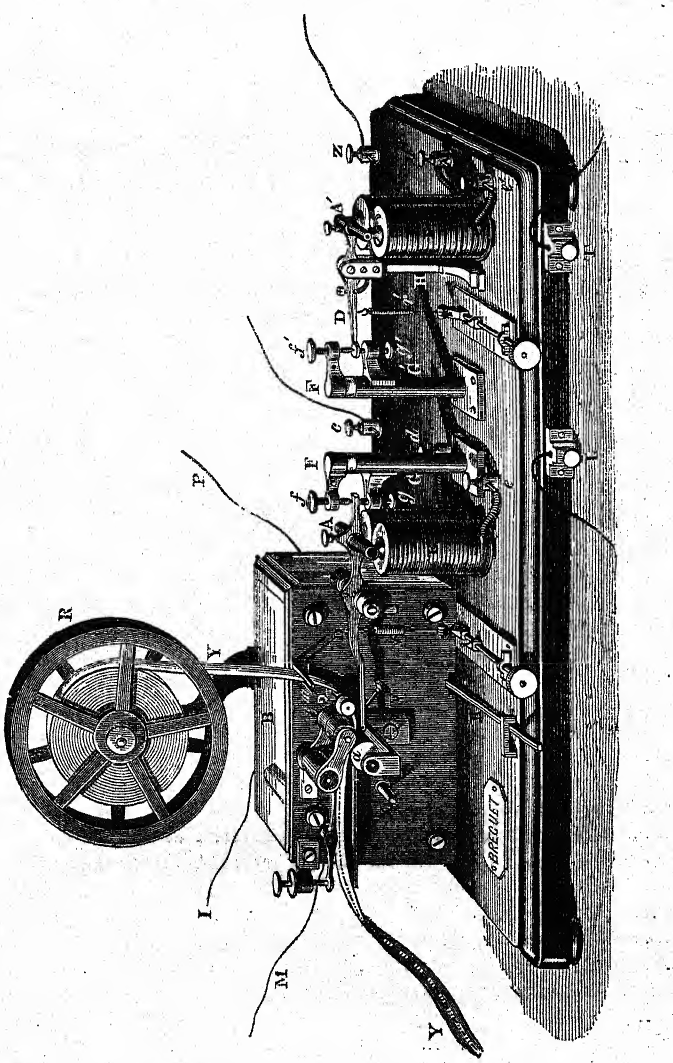
Fig. 40.



V, which passes through the lever, and the point of which can be adjusted to any degree of projection. A steel point, *t*, is attached beneath the longer arm of the

lever, and two contact pieces of brass, a and b, are fixed beneath these points. A small spring, r, serves to keep the lever in its normal position, V being in contact with a, and t separated from b. The lever is in connection with the line-wire through the fulcrum S, and the binding-post C; b is in connection with the positive pole of the battery through B; and a is in connection with the instrument through A.

Fig. 41.



Thus, in the state of repose, when V and a are in contact, a current coming from a distant station passes from V to a and to the earth through the instrument. When P is depressed, a positive current is transmitted on the line to the distant station, and

series of such currents of different durations and at various intervals can thus be transmitted by the operator, producing corresponding signs on the receptor of the distant instrument, but which do not pass through his own instrument.

In the original form of the Morse instrument, and which is still very generally employed, considerable force is required to emboss the signals on the paper, and the currents arriving at the station being in general too weak for the purpose, an instrument known as a relay is used to put in action a *local* battery of sufficient power to produce the required effect. These relays are of various forms; one of the simplest is shown in fig. 41, which is a view of a complete Morse instrument of a pattern very generally used throughout Europe. A modification has lately been introduced, which will be explained further on. The relay is on the right. E′ is an electro-magnet wound with a great length of fine wire (having a resistance ordinarily of about 120 miles); a metallic support, H, carries a lever, D′, to one end of which is attached the soft iron armature A′, in the form of a split tube, with the view of getting rid of residual magnetism, as far as possible, from the part which approaches the electro-magnet; the other end of the lever works between the points of the two screws f' and g' : g' is insulated and supported by the hollow pillar G′; f' is connected to a rod of metal inside this pillar, and insulated from it. A spiral spring, r', is adjusted so as to draw D′ away from f' when in a state of repose, and f' is so adjusted that when the armature A′ is attracted by the electro-magnet, they cannot *touch* one another, being prevented by the contact between f' and D′; D′ is in connection with the zinc of the local battery through H and Z; f' is in connection, through F′ and e, with one end of the coil of the electro-magnet E, which works the apparatus. The copper pole of the local battery is in connection with the other end of the coil of E through c and d.

The current from the distant station arrives at L, passes to e', and through the coils of the relay magnet to d', and so to the earth through T; E′ becomes magnetic, attracts A′, and makes a contact between D′ and f', thus completing the circuit of the local battery through the electro-magnet E. The electro-magnet, E, has an armature, A, which is attached to a lever, D, adjusted in the same manner as D′, by two screws, f and g, insulated from one another, and a spiral spring, r; the other extremity of D carries a screw-point, V, placed opposite to a groove in the barrel, b, and adjusted so as to be in contact with it when E attracts A. A ribbon of paper about half an inch wide is coiled on the drum R, passed through the guide m, under the spindle O, and between the two rollers b and a, which grip the paper between them and draw it through at an uniform rate, as a rotates by the action of clockwork inside the metal case B. The clockwork is set in motion or stopped by moving the lever k to the right or left.

To receive a message, the clockwork is set in motion, and, as each pulsation of electricity which arrives from the distant station communicates magnetism to E through the means of the relay and local battery, it attracts A with considerable force, and presses the point of V into contact with the paper ribbon as it is drawn through the rollers, and according as the duration of the current of electricity is longer or shorter, a longer or shorter mark is embossed on the paper. The moment the current ceases, the spring r draws the point away again from the paper. By the combination of *dots*, *dashes*, and spaces thus produced, the letters of the alphabet are represented, and words can be transmitted at an average of 20 in a minute.

A galvanometer is generally attached to a Morse instrument to indicate the passage of a current of electricity. In the embossing instrument it is not absolutely necessary, because the attraction of the armature by the local battery current makes a considerable noise; but if not carefully adjusted, the armature sometimes adheres to the magnet, and in this case no signal would be given, and the galvanometer would prove of value: it is, therefore, generally used.

Instead of embossing the signals on the ribbon of paper by mechanical pressure, Mr. Bain adopted the method of saturating the paper in a solution of prussiate of potash, and passing it over a brass wheel in connection with the positive pole of the local battery, the negative pole of the battery being connected with an iron point, which is kept in contact with the paper by a spring. A chemical decomposition is thus produced by every current which passes, resulting in the formation of ferrocyanide of potassium, or Prussian blue, in which colour the signals are printed. An acid solution was used at first, but it has been found better to employ an alkaline solution of the salt, viz.:—

As used in France:—

Water	100 parts.
Nitrate of ammonia	150 ,,
Prussiate of potash	5 ,,

Or, in England:—

A saturated solution of nitrate of ammonia in water		1 part.
Ditto	prussiate of potash	1 ,,
Water		2 parts.

Liquor ammonia sufficient to make the solution decidedly alkaline.

The paper preserves its moisture better when the alkaline solution is used; it is also cleaner and the marks do not fade.

When stations are near together, and local batteries can be dispensed with, signals can be transmitted more rapidly by means of Bain's instrument than by the ordinary Morse instrument, because there are no levers to be set in motion; but a powerful current of electricity is necessary to overcome the resistance of the damp paper and to effect the decomposition of the salt; hence local batteries are generally necessary, having from 12 to 18 cells arranged for tension. Bain's modification of the Morse instrument has been extensively used in England; but it has been found to be more troublesome and expensive than the ordinary Morse, and is being gradually given up. In Bain's original telegraph the transmission was effected automatically. Holes to represent the dots and dashes were punched by hand in a strip of paper, which was passed over a metal roller, and a brass wire pressing on the paper came into contact with the roller for a longer or shorter time as the punched holes representing dots or dashes passed underneath it. The wire was connected with a voltaic battery, and the wheel with the line wire, and thus at every contact a current was transmitted on the line.

The receiving apparatus was the same as above described. This method of transmission has been tried with various modifications at different times; but no automatic system has been found satisfactory. The frequent slight perturbations which occur in the system of conductors, sources of electricity, and instruments, can only be successfully overcome by the manipulation of an intelligent telegraph clerk; and no system of telegraphy which has been based on the purely mechanical transmission of a dispatch has been found successful hitherto.

The most valuable improvement on the Morse instrument is that patented in France by MM. Digney Frères, and in England by Messrs. Siemens and Halske.

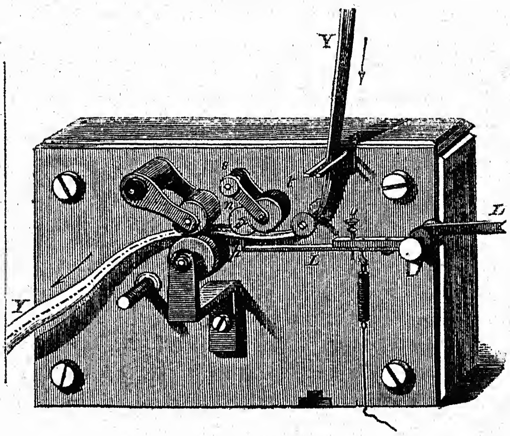
The general arrangements of this instrument are the same as those shown in fig. 41; but the signals, instead of being embossed on the paper by simple pressure, are printed in ordinary printer's ink.

The mechanism by means of which this is effected is shown in fig. 42, which represents the recording part of the instrument, the remainder being identical with fig. 41. *n* is a small wheel about the size of a fourpenny piece, which revolves on its axis at

an uniform rate by the action of the same clockwork which unwinds the ribbon of paper. t is an ink-roller, by means of which the edge of n is kept constantly supplied with ink. The pen lever, L, is made very light, and carries at its extremity a small projection, p, on which the paper is supported as it is wound off the reel. The height of p is so regulated by the adjusting screw o, that the paper passes just below n without touching it.

When a current of electricity circulates through the electro-magnet it attracts the armature, moves the lever L, and raises the ribbon of paper which rests on p, until

Fig. 42.



it touches the edge of n, when either a *dot* or a *dash* is printed according to the duration of the current. It will be observed, that the amount of work to be done by the electro-magnet in this arrangement is very small; it only has to lift an inch or two in length of the ribbon of paper through a distance of say $\frac{1}{20}$th of an inch. No mechanical pressure need be exerted, it is sufficient if the paper touches the ink on the edge of the wheel n. Hence the current arriving by the line wire from a distant station has always sufficient force to work this apparatus, without the intervention of the relay and the local battery, which can be entirely dispensed with.

The ink printing instrument has been adopted in France, after the experience of two years; but trade interests have hitherto limited its use to a few of the smaller telegraph companies in England.

In Australia, the Morse instrument has been adopted for all the government lines of telegraph; magnetic instruments are used in combination with relays and local batteries. The electro-motor is the same in form as the single needle instrument, fig. 36, except that the needle is suppressed, the current generated by the magnets being transmitted directly on the line; it works a relay on the same principle as the needle at the distant station, setting in action the local battery which records the signals by means of an instrument similar to fig. 41.

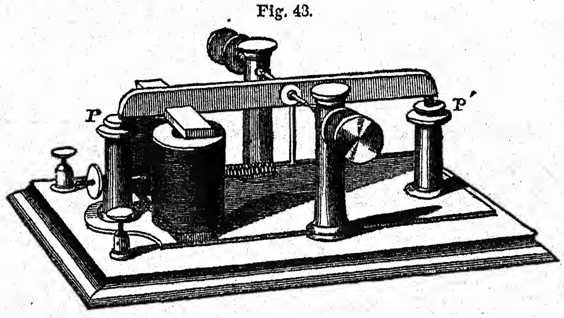
The manipulation of this instrument is not so easy as that of the ordinary Morse; greater mechanical force being required to move the lever; but in practice this is said to be no real impediment. The question of insulation has already been alluded to.

A simple and inexpensive system of working several Morse instruments in circuit is used on some of the shorter English lines. Only one battery is employed, and a current is sent constantly on the line, passing through galvanometers at all the stations,

and to earth at the terminal station. The galvanometers are all deflected in the same direction. When any station wishes to communicate, the operator breaks the circuit, and all the galvanometers return to zero ; he then, by making and breaking contact by means of the ordinary key, can transmit a message which is recorded at each of the stations. A similar system is universally adopted in America, even on their longest lines. *Main* batteries are provided at intervals of from 200 to 300 miles along the line, which are set in action by relay magnets, by the current arriving from a distant station. All the intermediate stations are provided only with relay magnets, local batteries, and transmitting keys. The current being continually sent on the line, any operator can break it by depressing his key, when all the relay magnets are affected along the whole line, the local batteries set in action, and a signal transmitted. This action, it will be observed, is the reverse of that usually adopted in Europe, and it has undoubted advantages, requiring fewer batteries ; and if the Daniel battery be used, the expenditure of zinc is nearly compensated for by the smaller quantity of copper reduced upon it.

In America, the recording apparatus has been very generally dispensed with, and messages are received by *sound ;* the relay being employed to work a *sounder*, so arranged as to make a distinct rapping noise, which can be translated by an expert operator with perfect ease. One of these *sounders* is shown in fig. 43. The armature

Fig. 43.



is attracted to the electro-magnet when the local battery is set in action, and strikes forcibly against P ; when the current ceases, the balance-spring brings the lever back to its state of rest, and a feebler sound is produced by the contact at P′. The *intervals* between the long sound and the slight tick of the return sound represent the *dot* or the *dash*, and the intervals between the occurrences of these two complementary sounds represent the spaces.

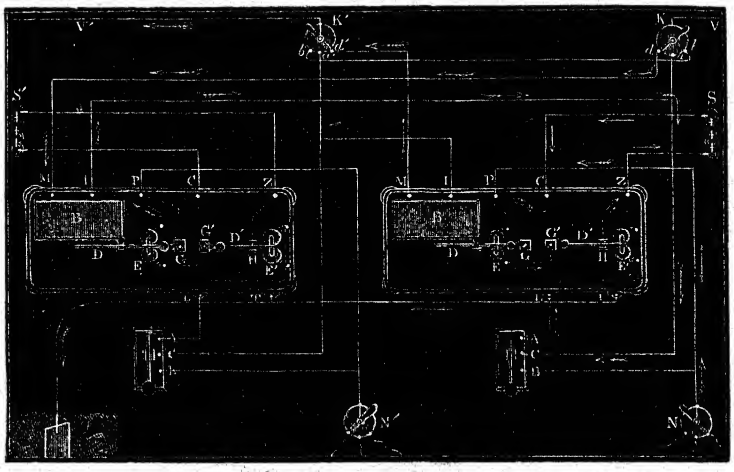
In Europe it is considered to be of great importance that the messages sent should be directly recorded by the instrument, both as a check upon the operators, and as an additional security in the transmission of messages correctly, and the recording apparatus is still retained.

The power of receiving messages correctly and quickly by sound, is said to be confined to a comparatively small number of persons, and that many who can receive well by eye, are not able to do so by ear ; but authentic statistics on this point are much required.

When very distant points are connected by electric telegraph wires, a system of relays is employed, the line being worked in circuits of from 200 to 300 miles. The current, starting from A, travels to B, sets in action another voltaic battery there by means of a relay, and passes to the earth. A fresh current is thus established at B, which travels to C, and there loses itself in the earth after setting in action another

voltaic battery, and so on. The distance to which telegraph communication can be carried in this manner appears to be without limit. When Morse instruments are used (as is almost invariably the case) upon such long lines, two instruments are generally placed at each intermediate station, so arranged that each station may communicate independently with its neighbours on both sides at the same time, or that the whole of the stations, or any number of them, may be placed in connection for through correspondence. The connections with a double Morse instrument at an intermediate station on a long line are rather intricate; they are represented in fig. 44. K K′ are

Fig. 44.



two commutators in connection with the line wire, V V′, entering the station on either side. Each commutator has three wires leading from it. When the handles are placed at *b b′*, the current passes directly from V to V′ without passing through the intermediate station. If the handles are placed at *a a′*, each instrument at the intermediate station can communicate with the line on its own side only, but should it be required to communicate between the terminal stations through all the intermediate stations, the commutators are placed at *d d′*. In this position we will trace a current coming from V. Its course (indicated by the feathered arrows) is from *d* to M, whence it passes through the metallic frame of the left hand recording instrument to the pen lever D, which, being in its normal state in contact with the upper screw of the pillar G (fig. 41), allows the current to pass to I, thence to C, the manipulator of the right hand instrument, and so through L to E′, the relay magnet, setting in action the local battery S, which prints the signal, while the current which we have traced passes to the earth by T. But in printing the signal in this right hand instrument, the lever D is depressed, and a contact is made at G between its main battery and the line wire V′, the current passing from N to P through the contact at G, through D, the metal frame of the right hand recording instrument B, to M, and so to *d′* and V′.

When two instruments are thus arranged, the currents which arrive from a distant station pass to the earth, after setting in action fresh currents generated in main batteries placed in the station. One of the instruments acts merely as a conductor, and the other both as a recording instrument and a relay. When intermediate stations are not considered of such importance as to require two instruments, a double relay magnet is frequently used with one instrument. These are arranged in such a manner

that a current arriving from either side completes the circuit of the local battery, and works the register; while, by means of a commutator, the clerk at the station can send a message in either direction, or allow the current to pass on to the next station.

In the ordinary relay magnet the armature is drawn away from the electro-magnet by a small spiral spring, whose tension must be constantly re-adjusted according to the variations in the power of the current, the various disturbing influences acting upon the line wire, and the amount of residual magnetism left in the core of the electro-magnet on the cessation of the current, and which tends to retain the armature. Moreover, the force of this spring always acts against the attraction of the electro-magnet, and requires a certain electrical force to overcome it.

These disadvantages have been overcome by using reverse currents, instead of a succession of currents in one direction only. Many different relays have been constructed on this principle, but two only will be described. They all depend upon the employment of permanent magnets, instead of, or in combination with, soft iron armatures, so as to bring into play the attraction and repulsion of opposite or similar magnetic poles.

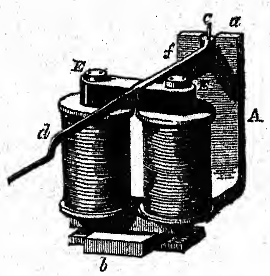
Varley's relay, as used by the Electric and International Telegraph Company, consists of an electro-magnet, the core of which is moveable, inside its helix the latter being fixed. The core is delicately mounted on pivots, and its extremities play between the poles of fixed permanent magnets of a horse-shoe form. The negative current magnetising the core in one direction causes it to be attracted to one side of the permanent magnets, and thus performs the part of the spring in the ordinary relay, opening the local circuits. The reverse current, reversing its magnetic poles, causes it to be attracted in the opposite direction, and closes the local circuit.

This system is particularly advantageous in working through submarine cables, the reverse currents assisting materially in overcoming the retarding influence of induction. The transmitting key is arranged by Mr. Varley so that a momentary contact with the earth, or with a weak battery, is made after breaking the contact between the line wire of one pole of the battery, and before making the contact with the other pole, thus allowing the charge of the wire to escape to earth, or be neutralised. This momentary contact with the earth is not used by other telegraph engineers.

Mr. Siemens has a very delicate and ingenious relay, which is specially adapted for induced currents of electricity.

Siemens' relay (fig. 45): A is a strongly magnetised bar, bent at right angles, and carrying a horse-shoe electro-magnet on its south pole. Both of the soft iron connections, E E′, have therefore communicated to them south polarity. *f* is a light bar of soft iron, moveable on a vertical axis, *c*, fixed in the north pole of the magnet, and terminated by a light arm of platina, *d*; *f* is consequently north polarity, and is attracted by both E and E′. *f* is in metallic connection with one end of the coil wire of the relay magnet, and its platina arm, *d*, is confined between two adjusting screw points, the one being insulated, the other in connection with the local battery. When a current of electricity traverses the coils of the electro-magnet, it tends to increase the south polarity of E, while it diminishes the south polarity of E′, or reverses it according to the strength of the current. *f* is no longer in equilibrio, and moves to the side on which it is most strongly attracted, butts against the screw point connected with the local battery, and puts it in action. This relay is designed to be

Fig. 45.



worked by induced electricity, the reverse current reversing the poles of the electro-magnet, and bringing *d* back into its original position. If voltaic electricity be used without reversals, the screw points are so adjusted that *f* is always nearer to E′ than to E. A positive current circulating through the electro-magnet destroys the equilibrium, and draws *f* towards E. On the cessation of the current, *f* being nearer to E′ than to E, and their attractions being now equal, it is drawn back to its position of repose.

In this relay the use of the adjusting spring is avoided, but the full value of the suppression of this adjustment is only obtained when reversed currents are employed. When the signals are made by simply making and breaking contact with the battery, an opposing force is evidently necessary to bring the lever arm of the relay back into its original position, and this force must be adjusted to balance the force of magnetism produced by the current coming from the distant station and circulated through the electro-magnet of the receptor, which is very variable, depending upon the state of the weather and the perfection of the battery, &c., and necessitating frequent delicate adjustments; but when reversed currents are used, the action of one current balancing that of the other, no adjustments are necessary.

The most perfect printing telegraph which has been invented is that of Professor Hughes, which prints the message in Roman characters on a band of paper. The following brief description is taken from the report of Mr. Latimer Clark; for fuller details, *vide* Prescott's 'History of the Electric Telegraph.'

The instrument contains a type-wheel upon which are engraved the letters of the alphabet, and which is kept constantly revolving at an uniform rate by means of clockwork and an escapement controlled by a stiff spring which vibrates 3000 times in a second. The efficiency of the telegraph depends upon the synchronous motion of the type-wheels at the distant stations, and Professor Hughes has found the spring to be the most reliable governor. On a shaft in connection with the type-wheel an arm is carried, which sweeps round on a horizontal table performing the same number of revolutions as the type-wheel itself. The table has twenty-eight small moveable pins on its circumference, corresponding with the letters on the type-wheel and in connection with keys like those of a piano. When a key is depressed, its corresponding pin is raised, and the arm of the type-wheel in the course of its rotation comes in contact with it, and by a peculiar arrangement transmits an electric current along the line. The receiving part of the instrument is provided with an electro-magnet, which, as soon as it is acted upon by the current, disengages an apparatus connected with a band of paper, which it raises momentarily into contact with the type-wheel, and the letter which happens to be opposite to it at the time is impressed. The paper is not only raised into contact with the type-wheel, but is for the moment borne forward at the same velocity as the wheel, and the impression, therefore, is very perfect. It will be evident that if the type-wheels of two instruments are adjusted so as to revolve at the same speed, the same letters will always be passing the corresponding points on the two tables carrying the moveable pins at the same moment, and an instantaneous current of electricity acting on both magnets at once will print the same letter on both instruments. A peculiar and original form of electro-magnet is employed in this instrument. The two poles of a permanent horse-shoe magnet are prolonged by cylinders of soft iron surrounded by coils of wire, and provided with an armature of the usual kind. The armature which lies in contact with the soft iron poles of the magnet is held fast by the attraction of the permanent magnet; but this attraction is counteracted by an opposing spring, which is so adjusted as almost to overcome the force of the magnet. In this state of things a very feeble and momentary current of electricity circulating in the coils of the electro-magnet, and

producing opposite polarities to those permanently given to the soft iron core by contact with the permanent magnet, so weakens their attractive power that the armature obeying the force of the spring flies away, and in so doing prints a letter; the next instant it is again mechanically forced into contact with the electro-magnet, and is ready to be released again by a succeeding current. The action of this electro-magnet is very much more rapid and certain than that of any other form yet invented, and the instrument appears peculiarly adapted to telegraphing through long cables, in which the retardation of the current due to induction is so formidable an enemy to rapid signalling.

Mr. Latimer Clark says: "By the ordinary Morse system of printing, each letter is composed of three or four distinct lines or dots, requiring as many complete electrical waves or reversals, with a sufficient duration of time on some of them to distinguish between dots and dashes, and between the spaces which divide portions of letters and those which separate whole letters or words. By Professor Hughes' system each complete letter is formed by a single wave, or even by a half wave or reversal, and the spaces are formed by the mechanical action of the machine and occupy no appreciable time. The instrument has been seen to work with ease and accuracy at the rate of sixteen words per minute through a cable which would only admit of six words per minute being sent by the ordinary apparatus; and through the same cable it has been seen to work whole days without printing a single false letter."

Copying Telegraphs.—Mr. Bakewell was the first who accomplished the feat of constructing an electric telegraph which should reproduce at a distant station a fac-simile of a message written at the sending station. The principle of his telegraph was as follows: The message was written on a sheet of metal in some non-conducting ink, such as red sealing-wax varnish. The metal sheet was then put in connection with the line wire and moved in a circular or spiral manner beneath a metal style which was connected with the positive pole of a voltaic battery, the negative pole being put in communication with the earth. At the receiving station a sheet of chemically prepared paper placed on another metal sheet was moved in a similar manner under an iron style; the style being in connection with the line wire and the metal plate with the earth. From this description it will readily be understood that, as long as the style at the sending station was in contact with the metal sheet, a current of electricity would traverse the circuit, decomposing the salt in the paper and producing a line; but when the style at the sending station was passing over the varnish no current would circulate, and no mark would be made at the receiving station. A number of parallel lines thus traced on the paper with spaces corresponding to the varnish on the plate at the sending station, would reproduce in white on a ground of blue lines whatever might have been traced on the metal plate.

This system, although beautiful and ingenious, has not been found a commercial success, and has fallen into disuse; but it has been resuscitated with some modifications by the Abbé Casselli within the last year. He uses a relay and a local battery so arranged that when a current is circulated from the distant station the local battery is thrown out of circuit, and when the current ceases the local circuit is completed and the style marks the paper; the writing is thus reproduced in blue on a white ground.

The electric telegraph instruments which have been most generally used have now been described, and it would be out of place to go into further detail of the various instruments which have been invented; the works of Shaffner, Prescott, Gavarret, Gloesner, and Blavier, with numerous others, may be consulted by those who are desirous of further information on the subject.

For some years a solution was sought for the problem of communicating simultaneously in both directions by the same wire. This has been accomplished lately in a very ingenious manner by Mr. Siemens and others, by means of divided currents

and carefully adjusted resistances; a description of the exact manner in which it has been effected will be found in the French works above alluded to, but the system has not been found to work well in practice, because any error committed cannot be rectified until the whole message is completed, and the adjustments are too delicate to be preserved permanently. The former objection also applies to another system which has been proposed, namely, that of branch circuits instead of a continuous circuit. In this system station A is connected directly with B, and branch wires lead off from A B, at different distances from A, to C, D, E, terminating at each station in the earth; resistances are interposed at C, D, E, so as to equalise the divided currents, and a dispatch can be forwarded to all the stations from any one of them; but the arrangement requires careful adjustments, and is inconvenient for communications between intermediate stations.

Various auxiliary instruments are required in systems of electric telegraph, such as galvanometers, commutators, alarums, and lightning protectors. The two first have already been noticed; it remains to describe the others.

Alarums.—These are very useful in particular cases, but are not generally employed on the English telegraph lines, because it has been found that the employés become more careless when alarums are used than when the slight ticking of the needle or the electro-magnet is the only sound emitted by the instrument. Alarums add also to the expense of the apparatus; they require more powerful currents of electricity to work them than are necessary for working needle instruments, and they are more liable to get out of order.

They may be classed as alarums with clock-work, and alarums which are worked by the direct action of the electric current.

In the alarums with clockwork, the function of the current of electricity is merely to produce temporary magnetism in the soft iron core of an electro-magnet, causing it to attract its armature, which is made in the form of a lever lightly pivoted and having a small hook at the extremity of the lever arm. This hook catches a projecting point on a wheel of the clock-work, and is held in that position by a light spring when the apparatus is at rest; when a current passes the armature is attracted, and the catch being drawn away from the wheel the clock-work moves under the influence of its main spring, and a bell is rung, either by the vibrations of an arm connected with an escapement, or by the rotatory motion of two arms attached to a wheel, and having hammers hinged to their extremities which fly out by centrifugal force and strike the bell, as in Professor Wheatstone's arrangement. It will be evident that an alarum so constructed may be as loud as we wish. The hammer which strikes the bell being moved by mechanical power, but, on the other hand, the catch which retains the wheel and keeps it from moving, must be carefully adjusted; if it have too light a hold a slight shake will ring the alarm, and if it is too stiff the electric current will fail to produce the required effect.

Fig. 46 shows an alarum worked by the direct action of the voltaic current. The armature L of the electro-magnet is a hollow cylinder fixed on a steel spring D, and furnished with a hammer M, which strikes the bell T. A spring *r* communicating with the earth by the binding screw E touches L when it is in a state of rest.

A current from the line wire passes from A to B, traverses the coils of the electro-magnet, the spring D, the armature L, the spring *r*, and so to the earth; but during its passage, L is attracted to the electro-magnet, the contact with *r* is broken, and the current ceases; L then falls back into contact with *r*, and the operation is repeated. In this manner a succession of blows are struck on the bell by the hammer M.

In order that this alarum may work with sufficient force an electric current of considerable quantity is required, and on long lines a relay magnet is employed in con-

nection with it. The arrangement of the relay is shown in fig. 47, which needs but little explanation. The current arriving from the distant station passes from L through the coils of the electro-magnet, and so to the earth at T, the armature *p* is attracted,

Fig. 46.

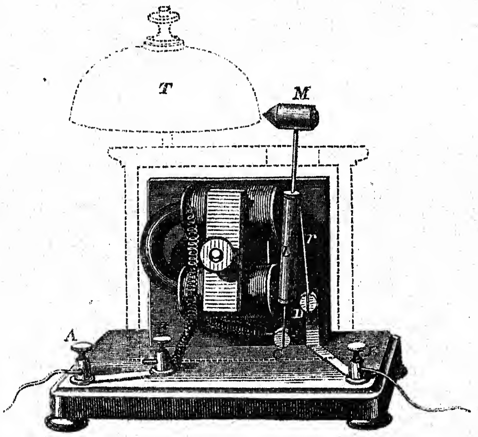
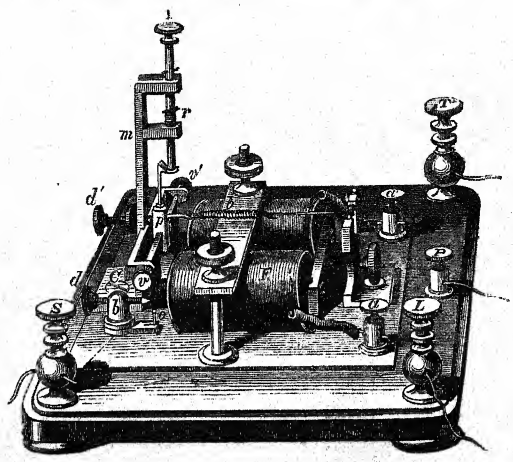


Fig. 47.



and the contact is made which puts in action the local battery; but at the same instant the button I is released and starts up under the influence of the spiral spring, *r*, and thus leaves a permanent record of the bell having been rung. This system is used when many wires from distant stations arrive at the same office; each wire has its relay, and there is but one alarum-bell; the relays are all arranged in a box having holes in the lid, corresponding with the buttons; these start up into view, when a current circulates through the electro-magnet coils, and designate the particular stations which wish to communicate.

Lightning Protectors.—When thunderstorms occur in the vicinity of systems of telegraph wires suspended in the air, powerful currents of electricity frequently traverse the wires, and entering the stations make great havock, if precautions are not

taken to preserve the instruments from injury. The effects produced upon the instruments, in such cases, are various, according to the quantity of electricity conveyed by the wires and its degree of tension ; but generally the fine wire in the galvanometers and electro-magnets is fused, the magnetic needles are demagnetised or have their poles reversed, and permanent magnetism is produced in the soft iron cores of the electro-magnets. More violent effects are produced in some cases. When underground wires or submarine cables have been connected with air wires, faults have frequently been produced by the passage of atmospheric electricity into the insulated conductor, which it has traversed until it arrived at some place where the insulating material was thin or defective. At this point the inductive force has become so great as to burst through the dielectric and destroy the insulation of the conductor. It is necessary, therefore, to adopt some means of protection in these cases, and happily the very high tension of atmospheric electricity enables us to apply an effective guard against its destructive effects.

(1). If a Leyden phial be discharged by means of a long and thin conducting wire, and if near the two ends of the wire are attached metal plates of considerable surface and in close proximity to each other, it is found that at the moment of connecting the ends of the wire with the outer and inner surfaces of the jar a spark passes between the two plates and a very minute portion of the electric charge circulates through the wire. (2) If the surfaces of the plates be covered with points they may be placed at a greater distance apart, and the same effect will be produced. (3) If the discharging wire be thicker and shorter than in the above case, and if near one of its extremities a very thin piece of wire of a metal which is a comparatively bad conductor of electricity be introduced so as to form a part of the circuit, this very thin wire will be fused by the electricity (if it be accumulated in sufficient quantity), while the thicker wire will remain uninjured. One of these three facts, or a combination of two or of the whole of them, forms the basis of all efficient lightning protectors, and the first is that which has been found most advantageous. Fig. 48 shows a lightning protector on this principle, much used in

Fig. 48.

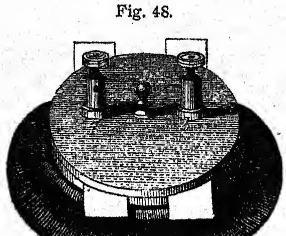
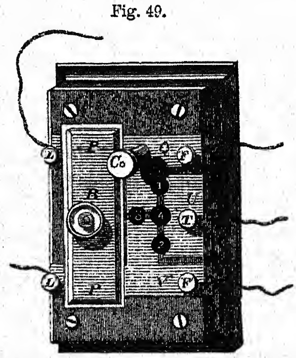


Fig. 49.



America, the two brass plates are about $2\frac{1}{2}$ inches diameter and $\frac{1}{16}$ inch thick ; they are insulated from one another by strips of dry paper or thin sheet gutta-percha. The upper plate is in connection with the line wire and the instrument by means of the two terminals, *a. b.* The lower plate with the earth. Lightning entering the station by the line wire leaps to the lower plate and passes to the earth, and the instruments are in safety. Fig. 49 shows another form of the same class of protector intended for an intermediate station, and which acts also as a commutator. By means of the metal plug C, and the holes 1, 2, 4, the line wire on either, or both, sides of the

station can be put in connection with the earth, or a through passage can be opened to the current without its influencing the instrument at the station by placing the plug at 3. This will be evident from the figure, the plate L Q F being in connection with the line wire entering one side of the station and one terminal of the instrument, and L′ V F′ being connected with the other side of the instrument and the other line wire. P B P is insulated from these plates by a strip of paper, and is in connection with the earth; U is also connected with the earth.

Fig. 50.

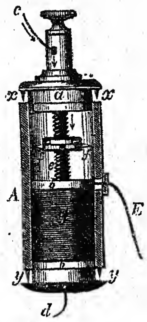


Fig. 50 shows a form of lightning guard in which the 2nd and 3rd of the facts alluded to are made use of. It is the invention of Mr. Walker, the superintendent of the telegraphs of the South-Eastern Railway Company, and has been successfully used on their lines for some years. The line wire is attached at c, the instrument at d, and there is a complete metallic connection between these points by the screw e and the very fine wire wound on g. A is a cylinder of brass, insulated from the line wire by box-wood, and in communication with the earth at E. The metal points at f, x, y allow the atmospheric electricity to escape to the outer cylinder, and so to the earth; while the very fine wire on g must be fused before the coarser wire in the instrument coils can suffer.

APPENDIX.

Electro-Magnets.—The laws which govern the forces of electro-magnets have been investigated by Messrs. Lenz and Jacobi, and also by Mr. Müller :—

If M denotes the magnetic force of the electro-magnet.
n the number of convolutions of wire.
d the diameter of the soft iron core.
Q the quantity of electricity in circulation.
and c a constant multiplier.

$$M = c\, n\, Q \sqrt{d}$$

This law only holds good for bars of iron, whose length is considerably greater than their diameter, for feeble currents of electricity, and under the supposition that the number of convolutions of wire is not so great as materially to diminish the influence exercised by the outer coils upon the bar of iron. These conditions are fulfilled in the electro-magnets usually employed for telegraphic purposes.

It will be noticed in the above formula that M increases directly as Q and as n; but Q decreases as n increases, supposing the electro-motive force to remain constant. Hence it is evident that a certain proportion between the resistance of the wire and that of the remaining portions of the circuit must be preserved to obtain the maximum magnetic force.

This relation has been found to be the following, viz. :—"When the resistance of the coils of the electro-magnet is equal to the resistance of the rest of the circuit, *i.e.*, the conducting wire and the battery, the magnetic force is a maximum."

The mathematical investigation of these laws may be found in Gavarret's 'Télégraphie Electrique.'

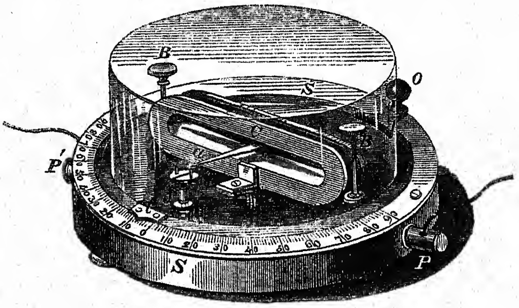
In practice it is usual to give the coils of the electro-magnets influenced by the currents of the main lines a resistance of about 120 miles, using No. 36 copper-wire; for the electro-magnets set in action by local batteries a thicker wire is used, giving a resistance of from 2 to 4 miles; but the thickness of the wire and the number of convolutions should be made in special cases according to the above laws.

It is very important that the best wrought-iron should be used in the cores of

electro-magnets, otherwise a considerable amount of magnetic force remains after the current ceases. This residual magnetism can seldom be entirely destroyed, but the more pure and perfectly decarbonised the iron the less is it perceptible. To guard against this evil, it is necessary that the armatures of electro-magnets should be very carefully adjusted so as not to *touch* the poles of the soft iron cores, and this more especially when the armatures are of magnetised steel, as is often the case. A thin piece of paper is sometimes inserted between the poles of the electro-magnet and its armature, or insulated stops are fixed in the face of the magnet to prevent contact.

The Sine-Galvanometer is used for the measurement of weak currents of electricity. A convenient form, used in connection with telegraphs in France, is shown in fig. 51, taken from Gavarret's treatise on the Electric Telegraph.

Fig. 51.



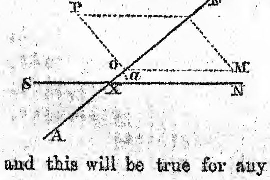
The magnetised needle is balanced horizontally on a steel point, and is placed in the centre of a coil of insulated wire. The coil is fixed to a horizontal disc, which has a movement of rotation on an axis inside a graduated circle, an index *t*, fixed to the disc shows the number of degrees it has moved with reference to the outer circle.

The ends of the coils are soldered to two binding screws P P on the outer frame, sufficient slack being left to allow of free motion of the disc and coils by means of a handle O. To use the instrument it is placed so that when the index is at zero, the magnetised needle is exactly parallel with the coil and in the magnetic meridian, the parallelism of the needle and coil is ascertained by the correspondence of a light index hand *a* fastened to the needle, and at right angles to it, with a line *f*; two studs placed on either side of *f* confine the oscillations of the needle within narrow limits.

The current whose force is to be estimated is circulated through the coils by means of the binding screws. The needle is immediately deflected, and the index abuts against one of the two studs at *f*.

The coil is now moved round to follow the needle, and this motion is continued until the two forces of terrestrial magnetism and the voltaic current exactly balance one another while the needle is parallel to the coil, and the directive force of the voltaic current is therefore acting at right angles to it. In this position the forces which hold the needle in equilibrium are represented in the subjoined diagram.

Fig. 52.



A F is the needle.

X, its centre of motion.

F its N. pole.

O M = P F, the force of terrestrial magnetism (= M).

O P = F M, the force of the voltaic current (= Q).

α, the angle of deflection.

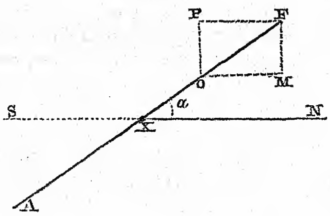
From inspection it will be seen that $Q = M \sin \alpha$, and this will be true for any angle of deflection in the quadrant, and any force of

electricity which is not so powerful as to deflect the needle fully to 90° ; M being constant and α being known, we have the means of comparing the forces of different currents when circulated through the coil of this galvanometer. Thus—

$$Q = M \sin \alpha$$
$$Q' = M \sin \alpha'$$
$$Q : Q' :: \sin \alpha : \sin \alpha'$$

For the measurement of more powerful currents, an arrangement called the *Tangent Galvanometer* is used. The principle of this instrument is, that if a very short magnetised needle be acted upon by a current circulated through a broad band of metal at some distance from it, it may be considered to be fully under the influence of the current at whatever angle it may be placed. The relation between the force of the current and the angle of deflection may be seen in the diagram, in which the letters are the same as before, but the force of the voltaic current acts at right angles to the magnetic meridian instead of at right angles to the needle.

Fig. 53.



O M = force of terrestrial magnetism(= M).

O P = force of voltaic current(= Q).

by inspection $M F = O M \text{ tang } \alpha$

or $Q = M \text{ tang } \alpha$

The instrument is placed so that the hoop is exactly in the magnetic meridian, and the current to be circulated through the hoop or band of metal.

The ordinary form of this instrument is shewn in fig. 54. A better form is shewn in fig. 55.

Fig. 54.

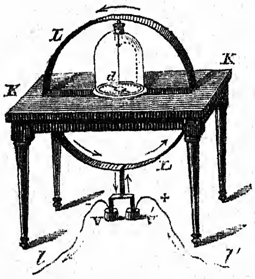
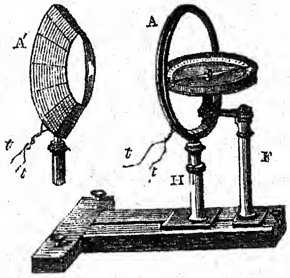


Fig. 55.



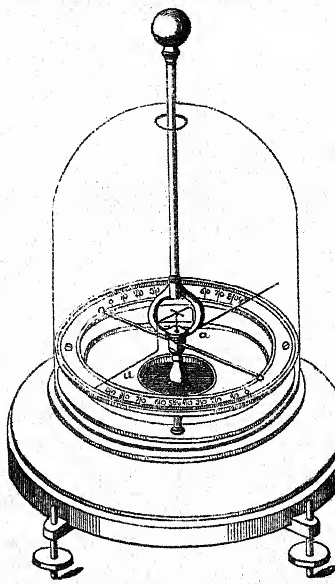
M. Gangain having discovered that when the needle is placed at the apex of an imaginary right cone, of which the circular conductor forms the base, and of which the perpendicular equals half the base, the voltaic forces are correctly proportional to the tangents of the angles of deflection.

Errors of construction are eliminated, and the force increased by placing a second circle symmetrically on the opposite side of the needle. And for the measurement of feeble currents a truncated cone of metal or wood, wound with fine insulated wire, may be advantageously substituted for the simple hoop of metal.

Milner's Electrometer. (From description in Report of Mr. Latimer Clark.)— "This instrument is the invention of Dr. Thomas Milner, of Maidstone, and was in all its essential parts described and figured by him in 1783, in a very talented little work, entitled, 'Experiments and Observations in Electricity,' by Thomas Milner, and published in London at that date. It is essentially the same in principle as Peltier's Electrometer, and may possibly be the parent of this latter very elegant instrument,

which was first exhibited in England by Professor Wheatstone, in 1834. Figure 56 shows Milner's Electrometer, as now constructed, and will enable the reader to understand the instrument at a glance. A brass stem rises from the centre of the wooden base, and is insulated from it by being screwed into a fragment of vulcanite, and surrounded by shellac poured in in a melted state. The insulated stem carries two brass arms, terminating in small knobs, and a little higher up it opens out into a loop or ring, through which passes an extremely light aluminium or other metal needle, supported by a light cap, which rests on a fine steel point; a short bar of magnetised steel is also attached to the needle, and tends to bring it to rest in a fixed position, with respect to the magnetic meridian. At some distance beneath the needle is a graduated circle, which is not insulated, and also a circular plate of looking-glass (marked *a a* in the figure) surrounding the stem. In reading the deflections, the eye is placed in such a position, that the needle covers its own image in the looking-glass, so as to avoid parallax. A glass shade covers the whole and is perforated at the top to allow the insulated stem to pass through without touching it.

Fig. 56.



"When in use, the needle is allowed to come to rest, and the instrument is so adjusted, that the two brass arms lie parallel to it, and nearly touching it, the two halves of the needle being so bent out in a vertical plane, as to allow this. The upright stem is then charged by contact with the pole of a battery, or any other source of electricity, and immediately the repulsive action causes the needle to diverge to an angle dependent on the strength of the charge, or degree of tension. It is a matter of indifference whether the stem be electrified, and the base connected to earth, or vice versâ, the deflection is in either case the same. When delicately made, 10 or 20 cells will readily cause a sensible deflection, and by the use of the condenser even one cell will do so, and so it is, in fact, as sensitive as the gold leaf electrometer. In practice it is better to use from 100 to 400 cells. In the experiments made by me, the deflection caused by 250 cells was noted; the cable under examination was then connected with the insulated stem, and charged with 500 cells, and the time was observed which elapsed while the instrument was falling to the point indicated by 250 cells, that is, to half its initial tension; in well conducted experiments, the result is remarkably uniform.*

"The time occupied by a charged cable in falling to half its original tension is theoretically constant, whatever be the number of cells employed, for although the electricity escapes faster with the higher tension, the quantity which has to escape is greater, and that in the same proportion; a well-made submarine cable in the present day will retain half its original tension at the end of 30 or 40 seconds.

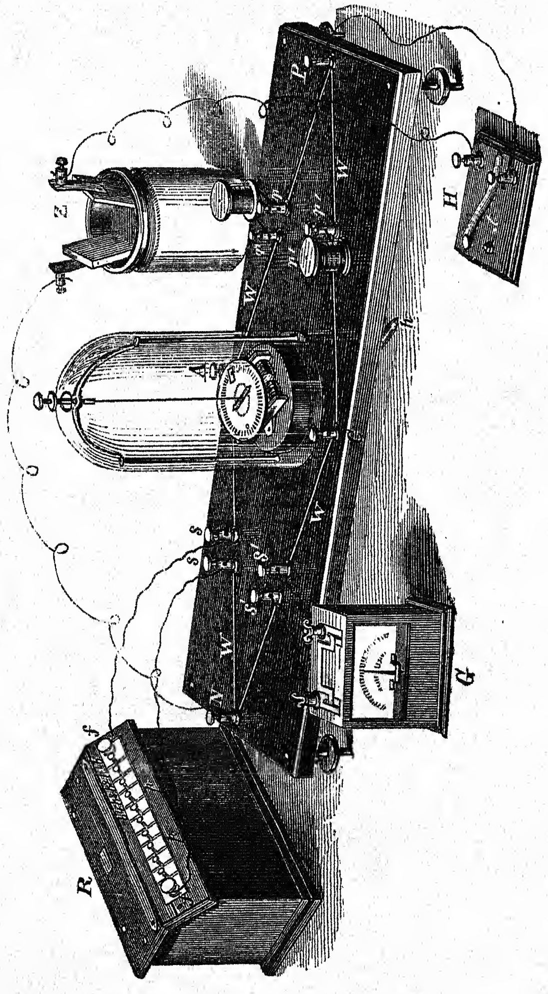
"This system has several important advantages, it is quite independent of the

* This method was used because the tensions are not correctly proportional to the deflections beyond 30°.—H. S.

length of cable under trial, and gives the same result with 100 miles of wire, as with 100 inches. It is also free from all errors arising from instrumental variation, the deflection due to the whole tension and the half tension being recorded afresh each day by actual trial. It is a very portable instrument, and requires no standard of comparison; all instruments, by whomsoever constructed, give directly comparable results. Lastly, it is capable of measuring with facility a minute escape of electricity in very perfect non-conductors, which would be quite inappreciable to the galvanometer. In very delicate experiments, it is necessary to dry the interior of the instrument by warmth, and by the use of small cups of chloride of calcium."

Wheatstone's Parallelogram (or "Bridge").

Fig. 57.



This beautiful instrument, the invention of Professor Wheatstone, affords a ready

means of determining with the greatest accuracy the electrical resistance of any particular conductor, as compared with a given standard, and is most useful in the practical operations of electric telegraphy.

Its construction will be understood from fig. 57. N A P C is a mahogany board 2 feet long × 10″ wide, fitted with levelling screws at its four corners, and a binding screw in the centre of each side; these binding screws are connected by a thick copper wire, W W W, let into a groove in the surface of the board, and forming a parallelogram N A P C. At points exactly equidistant from the angle N, the wires N C, N A are severed, and the ends are connected with binding screws, $s\ s$, $s'\ s'$. Similarly the wires P A, P C are severed and the ends connected with binding screws, $r\ r$, $r'\ r'$. In the centre of the board is a galvanometer, having a compound needle suspended by a fibre of raw silk in the centre of a coil of moderately thick wire. This coil is attached to a disc, A, moveable on a vertical axis, and a graduated card is fixed on top of the coils on which the deflection of the needle may be observed; a piece of talc is cemented to the card at 90°, to check the violent oscillations of the needle.

The ends of the coil are connected with the terminals C and A by wires, sufficiently long to allow of the graduated disc and coils being moved round by the handle, h, so as to bring the zero point to correspond with the needle when it is in the plane of the magnetic meridian. A single cell of a Smee or Daniel battery is generally sufficient to work the instrument: it is shown at Z, one pole being in connection with N, the other, through the intervention of a contact maker, with P.

To understand the action of the instrument, let us suppose the wire, W, to be unbroken at $r'\ r'$, $s'\ s'$; when contact is made at H, a current passes from Z to N where it bifurcates, and as the two wires N A P and N C P offer equal resistances, one half of the current passes through each channel, the currents reunite at P, and pass to Z, completing the circuit.

Neglecting the resistance of the external connections between Z and N, and Z P, which do not influence the result: if the electrical tension at N be represented by 10, at P it will be 0, and at A and C it will be 5, hence there will be no current between C and A, and the galvanometer will be unaffected. If now a resistance of 1 mile be introduced at s and an equivalent resistance at s', the current will bifurcate equally as before, but the tension at N, s', and s, will be much increased, and that at C and A will be diminished proportionately; but being still equal on both sides no current will pass from C to A, and the needle of the galvanometer will remain at rest.

If, however, the resistance introduced at $s\ s$ be either less or greater than the resistance interposed between s', s', the current will no longer divide itself equally at N; the distribution of the tensions in N A P and N C P will no longer be similar, the tension at C will be different from the tension at A, and an electric current will be established between C and A, causing a deflection of the needle of the galvanometer, and the direction of the deflection will denote on which side the resistance is greatest.

The general law of this instrument may be thus stated:—

The conductors N A P and N C P being united at N and P, the relation between the electric tensions at N and P must always be the same for both conductors, however the resistances of the conductors and the tensions may be varied. Hence the electric tensions at A and C will be equal as long as the following proportional resistances are maintained, N A : A P :: N C : C P (vide p. 639), and as long as the electrical tensions at C and A are identical no current will pass between them through the galvanometer.

It will now be clear that, having introduced into the circuit on one side of the parallelogram a conductor having an unknown resistance, we can determine its resistance by introducing known resistances into the circuit on the other side until the galvanometer being no longer affected, we know that the current is equally divided, and that the

resistances on both sides are equal. The mode of varying the resistances is by means of *resistance coils* and *rheostats*. The former are used for considerable resistances, the latter for those of smaller value. Resistance coils are simply coils of fine copper wire insulated with cotton and wound on bobbins, and of such length as to offer to the electric current resistances equal to so many miles of a standard conductor ; they are, of course, prepared with the aid of the "Parallelogram." The bobbins are arranged so that they can be introduced singly or in combination into the electric circuit.

A convenient form is that shown in fig. 57 at R. The coils are inside the box and their ends are soldered to the brass plates *p p*, which are insulated from each other. The small brass pins *b b*, when placed in the holes between the plates, form connections between them. *f f* are two binding screws for introducing the apparatus into the circuit. When all the pins are in their sockets the current passes from *f* to *f* through the brass plates *p p*, and the pins *b b*, the resistances of which are insignificant. If one pin b_2 be withdrawn the current is compelled to traverse the coil beneath it in passing from b_1 to b_3, and in this way any coil, or any combination of the coils, may be introduced into the circuit.

The Rheostat is an invention of Professor Wheatstone. The original form is shown in fig. 58, and a modified form in fig. 59, in the former a copper wire of about twenty

Fig. 58.

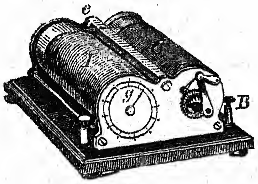
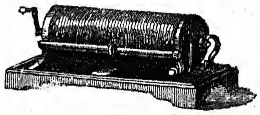


Fig. 59.



gauge is wound on an insulating cylinder I. A brass cylinder C is placed parallel to the former, and close to it, and the wire can be wound off one cylinder on to the other; the ends of the wire communicate by means of springs with the binding screws B B. When wound on the insulating cylinder the current of electricity is compelled to pass through the whole length of the wire; but when any portion of the wire is wound off I on to C, that portion of the wire is put in connection with the conducting metal of C and its resistance becomes practically *nil*.

The number of turns or parts of a turn on the insulating cylinder are read by means of a scale *e e*, and a graduated circle *g*.

This form of Rheostat is very perfect in its action, but it is troublesome to wind and unwind the wire, and if not carefully used the wire becomes loose on the cylinder, and one turn rides on another. A different form of Rheostat has been made by Mr. Becker, of Messrs. Elliot Brothers' firm, in which the wire is wound permanently on an insulating cylinder, and any number of turns are introduced into the circuit by means of a grooved wheel W, fig. 59, moving on a graduated bar *a a*. When the cylinder is made to rotate the wheel is screwed along the bar, or the bar may be pressed back by hand and the wheel slipped along it to any point desired. This form s very convenient, but it has one defect, viz., that the contact between the wheel and the wire is sometimes imperfect, and unless this be attended to great errors may arise from this source.

The contact maker is essential in observations with the parallelogram, as irrespective of the inconvenience of working without it, the temperature of the wire is increased by the continued passage of a current of electricity, and a source of error is thus introduced, owing to the varying conductivity of metals at different temperatures.

To bring the needle of the galvanometer to rest a magnetised sewing needle may be employed, and with a little practice it can be brought to rest so quickly that the delay which would otherwise result from its oscillations, each time that the current is made to pass, becomes quite insignificant.

In testing the conductivity of the copper wire to be used for submarine cables, the parallelogram is now extensively used. The electrical resistances of the coils of galvanometers or electro-magnets are also readily obtained by its aid.

Messrs Siemens and Halske avail themselves of the parallelogram, in discovering the position of a fault in a submarine cable during the process of manufacture. The ends of the cable are connected to the binding screws A C, the cable containing the fault of insulation being coiled in a tank of water, so that the fault forms an earth connection—one pole of the battery is attached to P and the other pole (through a contact key) to the earth. It is evident from this arrangement, that if the fault exist exactly at the centre of the cable the resistances on each side will be equal, and the galvanometer will not be deflected; but if it be nearer to one end—

Let R represent the resistance of the whole cable

x, y, the respective resistances of the shorter and longer parts from the ends to the point of leakage.

r, the resistance which must be added to x to make the tensions at A and C equal.

w and w' the resistances of the two sides of the parallelogram P A and P C, supposing them not to be equal, then we have—

$$w : y :: w' : r + x$$

and $R = x + y$

whence $\left.\begin{aligned} x &= \frac{w' R - w r}{w' + w} \\ y &= \frac{w R + w r}{w' + w} \end{aligned}\right\}$ or, if $w = w'$ as is usually the case $\left\{\begin{aligned} x &= \frac{R - r}{2} \\ y &= \frac{R + r}{2} \end{aligned}\right.$

This same method will evidently be applicable for discovering the position of a fault in the insulation of a submerged cable containing several conductors, as long as the insulation of one of the conductors remains perfect. Should there be no well insulated conductor between the extreme points, other modes of testing for the position of a fault in a cable must be resorted to. Messrs. Siemens and Halske have generally used the three following :—

I. Find a_i = insulation from one end.
b_i = ,, from the opposite end.
c = known resistance of cable when perfect.

II. ,, a = continuity from one end.
b = ,, from the opposite end.
c = as above.

III. ,, a_i = insulation, a = continuity } from the same end.
c = as above.

From these three sets of data the resistances x and y from the ends A and B may be derived as follows :—

From I. $x = \frac{a_i - b_i}{2} + \frac{c}{2}$

$$y = \frac{b_i - a_i}{2} + \frac{c}{2}$$

$$\text{From II.} \quad x = \frac{c\sqrt{u}}{1+\sqrt{u}}$$

$$y = \frac{c}{1+\sqrt{u}}$$

$$\text{where } u = \frac{a}{b} \cdot \frac{c-b}{c-a}$$

$$\text{From III.} \quad x = a - \sqrt{(a_i - a) \cdot (c-a)}.$$

These three tests may be compared and mean values of x and y deduced from them.

It is to be understood, that by the term *insulation* of a cable is meant its electrical resistance, when the far end is insulated; and that by the term *continuity* is meant its resistance, when the far end is connected with the earth.

The above formulæ are based on the suppositions that the cable contains only one fault, that the earth's contact is the same in both tests, and that it is not polarised, otherwise the equations will not give true results.

For further information on this subject, *vide* 'The Report of the Committee on the Construction of Submarine Telegraph Cables.'

Blank Form for Telegraphic Messages.

PREFIX——- Code time———No. of words———Time received———M. Time forwarded———M.

Signature of receiving Clerk———.

The following message, forwarded from-———and received at———186 .

From } D. To { Q.

Signature of person sending———.

Many of the illustrations in this paper have been copied from those in Gavarret's 'Téligraphie Electrique,' and some from Shaffner's 'Telegraph Manual,' and both these works have been largely consulted in its compilation.

W.

WATER MEADOWS, OR IRRIGATION.*

SECTION I.

This term is used in our own country to express the only system of irrigation which the routine of the farmers has allowed to be applied upon a large scale. It is true that the comparatively equal distribution of the rain-fall over the whole of the year, in the latitudes of the British Islands, renders the application of artificial

* By G. R. Burnell, C.E.

irrigation less necessary in them than it is in drier and warmer climates. But the climatological conditions of our wide-spread Colonies differ so vastly, that it is highly probable that Officers of the Corps of the Royal Engineers may be called upon to advise upon, if not to execute, works of this description in our more remote dependencies. In the following notice, therefore, the practice of other nations will be described even more in detail than that of our own, with a view of laying before the profession the results arrived at by the widest and most varied experience, and of furnishing a guide in the greatest possible number of cases.

The subject is, however, so vast, and our space so limited, that evidently many of its important parts must be omitted, or treated in a somewhat cursory manner. Indeed, as the application of water to agriculture involves the examination of the principles of structural botany, and as the means of distributing it trench upon the principles of hydrodynamics, it must be evident that it would be impossible to treat of them all within the limits of this article : it is proposed, therefore, to render it as succinct as possible by referring to the best authorities for an account of such principles as we may be compelled to notice without elaborate investigation.

HISTORICAL SKETCH.

Like all the other arts and sciences, irrigation appears to have been derived originally from the East ; for it is recorded to have been employed by the inhabitants of those regions from the earliest periods. In China, Assyria, and Egypt this mode of increasing the fertility of the land seems to have been coeval with the establishment of definite forms of society ; or at least the earliest records we possess of those nations mention the attention paid by the respective communities to irrigation. Of course, little faith is to be placed in the history of the Chinese ; but inasmuch as their traditions assert that considerable works were executed for this purpose about 2240 years B. C., it is to be assumed that the art of applying water to cultivated lands by artificial means is in that country of very great antiquity. Moreover, as rice is one of the the staple products of China, and as it cannot be produced, except under very peculiar circumstances, without irrigation, it is reasonable to suppose that the latter process must have occupied the attention of this singular nation at a very early period of its history. The extreme subdivision of property in China has however modified the application of the science of irrigation there ; because, as the fields are small, and manual labour perhaps at its lowest rate, the prevailing character of this class of works may be described by stating that the waters are usually raised by machines moved by hand, or occasionally by the labour of animals. These machines appear to be very simple, or, rather, imperfect. It does not appear that the Chinese are much in the habit of constructing irrigation canals on a large scale, or reservoirs to store flood waters (unless it be for the service of their canals), or longitudinal banks to direct or control the periodical overflows of their great rivers. In fact, this art, like all others, has remained in a rudimentary state in the hands of that nation.

In India the inhabitants appear to have early felt the necessity for, and to have taken measures to secure, an artificial supply of water to the agricultural districts not immediately situated upon the banks of the large rivers of the peninsula. To attain this object many vast canals were formed, conducting the waters of the Indus or the Ganges, or their tributaries, to the districts to be irrigated ; and large reservoirs were also formed to store the torrential rains which fall at certain periods of the year. The dimensions of these 'tanks' are frequently colossal ; thus, that of Bintenny, although now half-filled in, is said to have a circuit of about 8 miles ; that of Candelay has a circuit of about 4½ miles, with a depth of about 24 feet at the head ; that of Mainery has a circuit of about 20 miles, with a transverse dyke of not less than a

mile in length. In fact, every principle of legislation, religion, or superstition appears to have been made to co-operate with the extension of the system of irrigation, so indispensable for a nation subsisting almost entirely upon rice.

But perhaps the origin of this science may be traced to the Iranian Empire, alike the cradle of the arts as it was of the languages of the civilized world. All the authors who have treated of that singular nation,—with which, thanks to the labours of Mr. Layard, assisted by the profound science of Major Rawlinson, we are beginning to become, as it were, practically acquainted,—all have assigned a very remote antiquity to the 'Hanging Gardens of Babylon,' and even a more remote date to the irrigation canals upon the banks of the Tigris and of the Euphrates. One work upon the latter river may be especially mentioned; it is the artificial lake Nitocris, formed to receive the flood-waters of that river, for the double purpose of storing them and of preventing their destructive ravages. According to Herodotus, this lake had a circuit of 20 miles; according to Diodorus, the circuit was 75 miles. Under the rule of Mohammedanism, however, it has totally disappeared, together with nearly all the other works executed for similar purposes.

In Egypt, the peculiar character of the climate and of the Nile appears to have occupied the attention of the earliest legislators and rulers of the country. Immense canals were cut, by means of which the rising waters of that river were distributed over larger areas than they could reach naturally; and transverse dykes appear to have been formed to facilitate the deposition of the fertilising mud they contained, by constituting, as it were, so many ponds of still water. General Andréossy, in his account of the French expedition to Egypt, mentions in detail the nature of these works, and he states that in Upper Egypt they are even now tolerably perfect.

The canals, which served to conduct the waters during the inundations, became reservoirs when these had subsided; but, as they were necessarily at a low level, the waters were forced to be raised by artificial means. The Archimedean screw is said to have been invented by the philosopher from whom it derives its name, during his travels in Egypt; and it is certain that the noria was frequently employed in such positions as those alluded to. Many of these machines are even employed at the present day. But the most remarkable work executed by the ancient inhabitants of Egypt is unquestionably the lake Mœris, which served to store the waters of the inundations. Pomponius Mela states that the area of this reservoir was about 1500 acres; whilst, according to Herodotus and Strabo, it was double that size. It was formed by Menes, who also executed other very extraordinary works for the same purpose of regulating the inundations of the river, and of storing its waters against the dry seasons.

In Ethiopia and Nubia similar methods to those used in Egypt appear to have been anciently employed. In Palestine and Phœnicia irrigation was also adopted; but the usual practice appears to have been more confined to the watering lands by simple machines than by costly and extensive deviations of running streams.

The Greeks do not appear to have paid any attention to the useful application of hydraulics, either for irrigation or domestic purposes. Nor do the Romans appear to have devoted much attention to the former subject, whilst the latter occupied one of the most prominent places in their consideration. Cato and Virgil allude to irrigation, it is true; but, very singularly, no authentic remains of canals, water-courses, or reservoirs for this purpose, constructed by the Romans, have been found in any of their numerous possessions; whilst it would be impossible to cite a province in which vestiges of the colossal works they erected to secure the water supply of their towns may not be found.

In the middle ages, the Visigoths constructed several very important irrigation

canals in the South of France and in Spain; and the Arabs, who subsequently became masters of the latter country, continued the works of their predecessors, adding to them the construction of storeage reservoirs, and the application of the noria—a machine they introduced wherever they established their dominion. In Catalonia, Valencia, and Andalusia, the irrigation canals constructed by the Arabs are, even at the present day, in a very perfect state. Upon one of them, in Valencia, that of Almazora, is a syphon of about 510 feet in length, which would prove that the state of hydraulic science had reached a very advanced point amongst that anomalous people. In Upper Catalonia it is not uncommon to see norias set in motion by wind-mills, for the purpose of raising water to the upper districts.

In modern Italy the science of irrigation has made perhaps the greatest progress, and, singularly enough, it would appear to be the most practised in the districts formerly occupied by either the Gothic or Visigothic tribes. In the Piedmontese dominions, and in Lombardy, the most perfect system of irrigation which can be cited, perhaps in the world, exists; whilst in Central and Southern Italy very little has been done to apply to useful purposes the numerous streams descending from the Apennines. As many of our future illustrations will be drawn from Upper Italy, it may suffice at present to mention, that frequently the artificial water-courses of that country have been designed with a view to render them applicable to the purposes of irrigation and of navigation at the same time; and that in Piedmont many large reservoirs have been formed to store rain-waters.

In the South of France, also, the Gothic tribes introduced the system of irrigation. One of the largest canals formed for this purpose in the Eastern Pyrenees is called, even at the present day, after Alaric, and is usually believed to have been constructed by the orders of that conqueror, who would seem occasionally to have had ideas of a different nature from those usually attributed to him. In the centre and in the North of France partial irrigation is carried on by diverting some streams, and, like those in the South, they appear to be of very great antiquity. Storeage reservoirs for rain-waters exist only in the South.

In Germany, Holland, and Flanders, it is very rare to find any other kind of irrigation than that known in our country by the name of water meadows; nor do the means employed exhibit more ingenuity than those we are accustomed to at home. In fact, the climate of Northern Europe is far too moist to require any great outlay in securing an artificial augmentation of the prevailing characteristic; and the difficulty the scientific farmer has to encounter is rather the excess, than the want, of water. All these countries, like our own also in this, adopt the practice of 'warping' (which will be described hereafter), for the purpose of retaining the materials in suspension in the tidal waters of their estuaries.

America is still too fresh to require the application of science for the extraction of its agricultural wealth. There are a few water meadows in the alluvial plains of North America, but the science of irrigation, not being yet required, is of course in a rudimentary state.

General Principles of Irrigation.

It may be asserted, as a general rule, that there are no countries to which irrigation may not be usefully applied; but the atmospheric conditions of the intertropical and of the glacial zones are such as to render the economical results of the operation often very questionable in their cases. For, firstly, it is well known that as we proceed from the temperate zones towards the Poles, the average annual rain-fall tends to distribute itself more equally over the year, even if the total quantity be not greater. A general system of irrigation in such countries would necessarily cost as much as in any other; but the occasions for its use would diminish more and more as we approached

the Poles. In the intertropical regions, on the contrary, the excessive heats would require much greater quantities of water, and the class of vegetation thus called into existence would be of a nature so totally different from that aimed at in the temperate zones, that none of the present rules for the management of irrigation would apply. The most satisfactory results hitherto attained have been unquestionably those to be met with in the temperate zones, and it is to them attention will be principally directed. In our hemisphere they may be considered to be comprised within the 25th to the 57th degree of latitude, although, as is well known, modifications of the system are applied in much higher latitudes. In the southern hemisphere the zone adapted for irrigation may be regarded as being of about an equal breadth.

The *irrigable* region of the northern hemisphere may be separated into four subdivisions, founded upon the class of produce which characterises them. The first would be the zone in which rice is cultivated ;

The second, that in which the olive is raised ;

The third, that in which the vine is raised ;

The fourth, that in which wheat is the staple produce.

Like the zones adapted for irrigation, the subdivisions are not to be considered as defined by any regular line ; for the greater or less proximity to the ocean, the greater or less number of mountains in any of them, and the relative general dip of the surface, alter singularly the warmth, or the moisture, of any particular place.

In the neighbourhood of towns, in all the subdivisions, the production of garden vegetables gives rise to a peculiar kind of cultivation, which requires the application of water every day. The instances where this is effected by irrigation, properly so called, are very few, and the means usually employed are to raise the water requisite from deep wells by the simplest machinery possible. Some of these will be described in the subsequent parts of this article.

Reversing the order of the subdivisions, to consider the kind of produce most likely to be benefited by irrigation, it is to be observed, that unquestionably the greatest advantage to be derived from it is in the fourth zone and in the application to water meadows such as may be called 'natural.'

Artificial meadows also gain by it, and to such an extent, that it is asserted that in Spain and in the South of France the lucerne will yield as many as eight or nine crops in the year. In the North, there appears very little reason to doubt but that an extra crop might be obtained from this grass, or that the yield might be increased one-quarter. The sainfoin also gains by irrigation ; but as it is a hardy plant and grows tolerably in very dry situations, it is more particularly reserved for drier positions. It is a received axiom, however, amongst continental farmers, that the most beneficial application of irrigation is to natural meadows, and the practice of our own farmers in this is precisely similar.

Occasionally, in the most northern subdivision, it would be desirable to be able to irrigate corn lands, as in the year 1846. The expense, however, would always be too great for the benefit to be derived.

It may be as well to observe that by the term 'natural meadows' is meant such as have a vegetation of which the gramineæ form the base ; such as the phlœum pratense, lolium perenne, festuca sylvatica, poa pratensis, &c. The term 'artificial meadows' implies such as have a vegetation composed of the leguminosæ ; such as the medicago sativa, trifolium pratense, vicia sativa, &c. ; all of which latter class are sown regularly every year.

The waters used for the purpose of irrigation are not equal in quality, and care must be taken in their selection. Those which flow from forests, peat mosses, or such as contain large quantities of the oxide of iron, are but little adapted to such uses,

even if the two latter may not be considered positively injurious. As a general rule, those waters are the best which have been the longest exposed to the air, or in the proportion in which they have traversed fertile lands able to communicate some of their properties. It is on this account that the waters flowing through towns or villages are the most desirable. Streams which rise from the granitic or primary rocks are always more advantageous than those from the secondary formations. It would appear also, that they hold in suspension a considerable quantity of potassa; and this substance is in the greater number of cases required to correct the nature of the soil of the alluvial valleys. The waters from the secondary limestones develop the growth of the carex, and of some of the poorer gramineæ, precisely in the proportion to which they are able to hold in suspension or solution the salts of lime. Rocks of the argillo-calcareous character, or marls, yield springs of an intermediate character. But it must be always borne in mind, that the condition to be fulfilled by any water for irrigation being to correct the deficiencies of the soil traversed, it may frequently happen that calcareous waters may be the most adapted to improve the argillaceous formations to be met with in some of the primary districts.

Sea-water mixed with fresh, or the brackish water of embouchures, is highly fitted for irrigation; and cattle are known to eat the grass grown in salt marshes with remarkable avidity. It may, however, be stated generally, that a very simple criterion of the quality or adaptation of water to the purposes of irrigation may be found in the vegetation of the natural channel. If it be covered with a luxuriant vigorous herbage, and the latter be of a good quality, the water of the stream may be safely pronounced to be adapted for the proposed use.

The description of soil which derives the greatest benefit from irrigation is that which is the most permeable, and which is the most easily warmed. Compact, clayey lands, on the contrary, gain the least, because they absorb with greater difficulty the heat necessary to insure that the water should produce the greatest effect. Moreover, as such lands are very retentive, the water they hold produces a very injurious effect by cooling the ground when evaporation takes place. In this kind of soil then it is necessary to let the water on at intervals of some distance, according to the temperature of the season. In all these general remarks upon soils, it is to be observed, that although the word 'soil' only has been used, yet in fact the subsoil is far more important even than the superficial soil, and that they only apply to the former invariably. Indeed, if a stratum of clay be found upon a bed of gravel, it may be irrigated as fully as a lighter soil, whilst a sandy stratum upon an impermeable bed must receive the smaller quantity of water.

As to peaty lands in a dry situation, MM. De Girardin and Du Breuil state, that they require frequent irrigations, but so arranged that the waters should not remain long upon them. The water must be turned on in large masses, and made to circulate with great rapidity; for it has been found that the peat in such cases parted with a great portion of the acid and astringent properties it contained.

The epoch during which irrigation is most profitably employed depends to a certain extent upon the object it is desired to effect. In the first, second, and third zones, this is principally to develop the progress of vegetation by lowering the excessive heat of the soil, and to obviate the inconvenience of drought. In these cases, evidently the operation should be performed in summer. In the third and fourth zones, however, water is often turned over meadows for the express purpose of protecting them from frost, and consequently should be applied in the winter. But in all, if it be desired to secure the deposit brought down by the streams, it is advisable to irrigate between the end of the autumn and the beginning of spring, for it is at this period of the year that the largest quantity of sediment is brought down from the upper country. Indeed, if

a large quantity of sediment were brought down in summer, it would be necessary to shut off the stream, because the impalpable powder thus deposited upon the leaves of the plants would render them unfit for cattle.

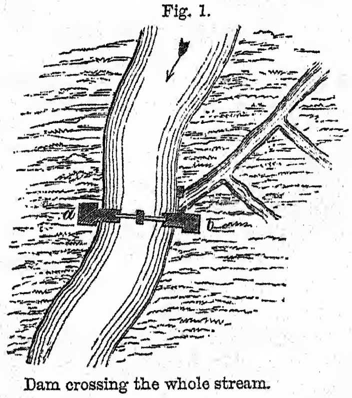
In warm weather, the time of day during which irrigation takes place is also to be considered. It has usually been observed that there is danger in applying it when the heat is the greatest, and that it is preferable to let the waters flow over the ground in the morning, or more particularly in the evening. When, however, irrigation is principally used as a preservative from frost, it should be applied during the whole day.

Very little is known with respect to the precise quantity of water necessary to irrigate a definite surface. Indeed, it must be difficult to arrive at any very precise notions upon this question, because the nature of the soil and of the subsoil, as well as the hygrometric conditions of the atmosphere, influence its solution. From observations made in the South of France by Nadault de Buffon, however, it appears that an acre of meadow land requires about 1200 cubic feet per day, during the season for irrigation. In more northerly situations it would certainly not be necessary to employ more than half of this quantity, even upon tolerably light lands.

There are certain primary conditions requisite to the establishment of a good system of irrigation, which may be briefly stated to consist in the facility for securing a constant supply of water, and such a configuration of the soil as to secure a regular current over it, and a perfect discharge for the water after it shall have performed its duty.

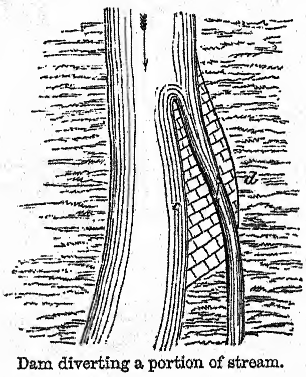
When the irrigation is to be effected by a running stream, to which the proprietor of the land has an undisputed right, so long as it is within his possessions, the deviation of the water may be effected either by a dyke or dam across the whole width of the stream, *a b*, fig. 1, or a portion only may be diverted by means of a spur, *c d*, fig. 2, or finally the transverse dyke may be made with a hatch so as to regulate the flow. A transverse dam across the whole stream is, wherever possible, the most desirable, because it enables the water to be penned back, and thus to be poured upon higher parts of the land : should this mode of raising the level of

Fig. 1.



Dam crossing the whole stream.

Fig. 2.



Dam diverting a portion of stream.

the water be adopted, care must be taken to prevent the flooding of upper lands belonging to other parties, and it must be borne in mind that the top water-line of an intercepted stream is never horizontal, but that it assumes a hyperbolic curve, joining the natural declivity at a distance varying with the inclination of the bed. If these means should not be sufficient to pour the waters over all the meadows,

it will be necessary to employ mechanical means. (*See* 'River Navigation,' section I.)

When the stream is of small volume, it is often found that the infiltration and evaporation from the leading channels will so diminish its yield as to leave hardly any water for the lower or remote portions. This may be remedied by the construction of reservoirs in which the water is allowed to accumulate, and from which it is distributed in flushes.

The construction of artificial reservoirs also furnishes the means of irrigating districts in which no natural water-course exists. By throwing a dam across the narrow gorge of a deep valley, in the manner frequently employed for canal reservoirs, it is easy to retain the rains falling in superabundance on the highlands during the winter months, which are subsequently poured upon the low lands in summer. For the mere purpose of irrigation, these reservoirs do not require to be constructed with the perfection necessary for canals. They may be made with a transverse dam of earth, if it be of a nature to resist infiltrations, and the outside either covered with turf or dry pitching. The crown of such a dam should have a width equal to half its height, and the base should be at least three times the height; the batter should be on the inside, towards the water, and formed in steps; it would also be preferable to make the dam convex to the inside. The top should be about two feet above the highest water-line, and two sluices are to be placed at the bottom, one for drawing off the water, the other for cleansing the bottom of the reservoir. The reader is referred to the article upon River Navigation, section 'canal,' for the details of the other precautions to be observed in the execution of these works, which might be made to render immense service to agriculture.

In Piedmont many such irrigation reservoirs have been formed; in Spain the Arabs constructed several very large ones,—amongst which, the one near Alicante may be particularly cited. In the Jura, and the department de l'Ain, in Switzerland, Hungary, and the Tyrol, the practice is sufficiently common, but in our own country it can hardly be said to have been tried unless upon the Duke of Portland's estate. The average proportions of the reservoirs in Piedmont seem to be such as to require a water surface of 1 acre to every 1½ acre irrigated, with a depth of about 1 yard to every 2 acres of water. Evidently, however, it is desirable that the depth be as great as possible.

The dimensions to be given to reservoirs must be influenced by the nature of the soil to be irrigated and the crop to be raised, far more than by any general rule; the climate of the district in which they are to be constructed must also be taken into account. We have seen that in the South of France 1200 cubic feet per acre per day are required; but if the soil be very permeable, and it should be impossible to make the water serve two or three times, much more would be required. Again, in the same region it is sufficient to irrigate five or six times after the first crop is carried, to secure a second, and an aftermath; but to calculate that a reservoir able to furnish from 6000 to 7000 cubic feet per acre would be sufficient, would lead to serious disappointment. For in this case the winter irrigation would not be taken into account, and probably it is more important than that during the summer months. If the reservoirs be well constructed, it is true that the excess of the heavy winter rains, and the greater volume of land springs, may effect this object; but it is far too important to be left out of consideration, and if the locality do not contain any natural resources for the supply of this particular branch of irrigation, the capacity of the reservoirs must be doubled. In many positions the heavy summer rains allow the reservoirs to be refilled several times; but experience has demonstrated that it is not prudent to calculate on this resource, and that it is advisable to make the reservoirs sufficiently

large to insure their being filled in the months from September to December included, to contain all that can arrive in them during that period, and to use the waste water for the winter irrigation. The precise quantity cited above is, however, only to be taken as applicable to the locality named: as was before said, in our more northerly climate, in all probability it would not be necessary to use more than one-half the water required to insure the perfect irrigation of the meadows in Italy or Southern France.

The remaining details of the application of a system of irrigation must depend necessarily upon the greater or less proximity of the supply, and of the local facilities for its application. The first condition to be attained is that the water spread over any surface should be able to flow away easily, and not to lodge in the lower portions; for directly it becomes stagnant, it develops the growth of noxious plants. From this arises the necessity for previously arranging the levels of the land to be irrigated, so as to attain the following conditions: 1st, the waters must arrive by the culminating points; 2nd, they must be distributed over the lower portions falling away from these points; 3rd, they must be collected in the outfall drains immediately they shall have passed over the land to be irrigated.

The arrangement of the surface of any land, in order to obtain these results, differs according to the natural configuration of the ground, which is found to be the most advantageous when there exists a natural declivity over the whole surface. In such cases as those represented below, nothing is required but to level the ground by filling up the lower points, A A, by means of the earth removed from the upper points, B B, so as to secure a perfectly even surface in the direction of the line C D. When the land is horizontal, it becomes necessary to create artificial inclinations similar to those mentioned, in order to facilitate the discharge of the water; and with this view a series of inclined planes are formed, beginning from the point where the water enters the field. The earth is removed from the lower parts of these depressions, and heaped up in the centre, so as to insure a double fall from the latter: each of these planes

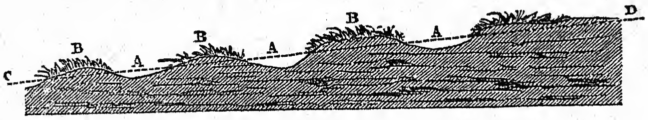


Fig. 3.—Section of land to be regularised for irrigation..

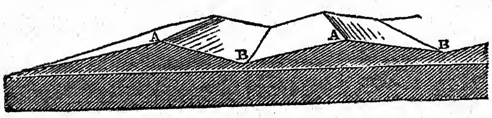


Fig. 4.—Section of land disposed in inclined planes to receive irrigation.

has at its culminating points, A A, a channel for the purpose of distributing the water and a drain at the lower points, B B, to receive and carry off the waters after they shall have produced their effect. The rate of inclination of these planes varies between 1 in 1000 to 1 in 100, according to the nature of the ground. In light and absorbent soils it requires to be slight, in order that the water may remain long upon them, and that it may not scour the ground; in compact heavy lands, on the contrary, the inclination ought to be greater.

The width of the planes is also regulated by the nature of the soil; the more compact this is, the wider the planes ought to be made; because the water can flow over a greater surface without being absorbed. In light and very absorbent soils the

planes ought to be narrower: the width in the first instance may be about 130 feet, whilst in the second it may be necessary to confine it to about 26 feet.

In all cases in which it is necessary to execute any earth-works in order to give the requisite form to the ground, it will be advisable to remove the turf in regular layers; when the works shall have been completed, this will be replaced, and carefully beaten down upon the soil, for the purpose of obtaining more rapidly a surface covered with grass of a good quality.

The *main conductor* receives the waters directly from the river, and conveys them to the *feeders*, which are usually placed at right angles to it, and which serve to distribute them over the surface of the meadow. This course is necessary, because if the feeders derived their supply directly from the river, and the volume of the latter were considerable, in the first place it would be difficult to regulate the flow, and in the second, if the stream should rise rapidly, it might hollow the land to a very serious extent. Evidently, if the river be small, there can be no reason why the feeders should not be formed directly upon it.

The main conductor takes its origin above the weir placed across the stream, and should be so directed as to convey the water to all parts of the land to be irrigated, and its banks should be made a little higher than the surrounding land, so as to insure a flow of water towards the latter, without its spreading irregularly over the sides. The feeders should, as far as possible, be arranged perpendicularly to the general inclination of the ground, as is represented in figs. 5 and 6, by the line E D. In some

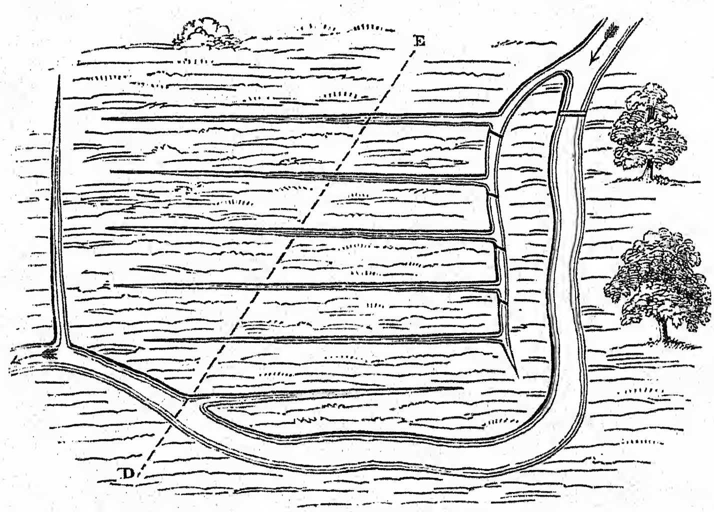


Fig. 5.—Irrigation by means of a main conductor.

cases it is necessary to form secondary feeders, in order to distribute the waters of the main feeders over the whole surface. These are directed to suit the general inclination of the ground, according to the line D E, fig. 6, and are placed at the summit of the inclined planes indicated in fig. 4.

The inclination of the main conductors and of the feeders is usually made about 1 in 500, which is sufficient to allow the waters to flow with a proper velocity, without injuring the bed. In proportion as the feeders are removed from the source of supply they must be diminished in dimension, in order that the waters may retain their initial velocity. It is usual to confine the length of the feeders to about 70 feet, and

when the surface to be irrigated exceeds that width, to construct secondary conductors; for the waters do not circulate with sufficient velocity when the length is

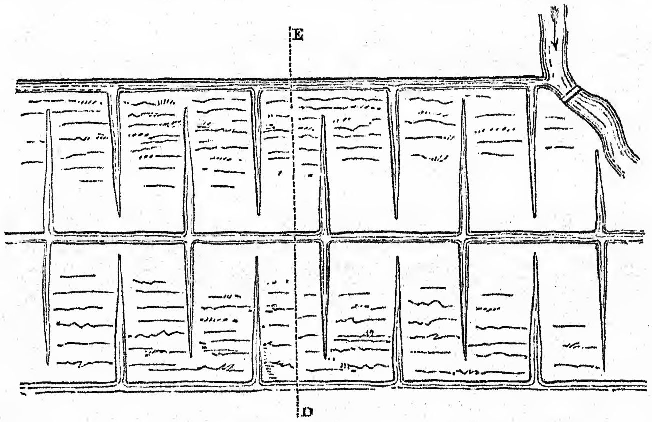


Fig. 6—Irrigation when the water is used twice.

greater than that above stated. The water which has flowed over the upper portion is collected in this case in the secondary channel, and made to irrigate a double portion of land.

Fig. 7.

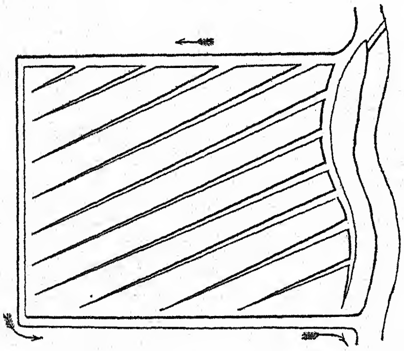
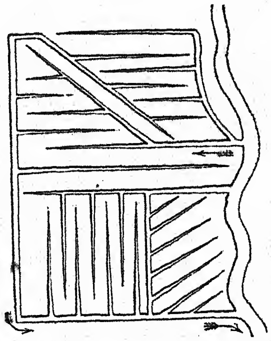


Fig. 8.



Irrigation when the surface of the land is with irregular inclinations.

In England, the process of irrigation generally takes place after the month of October, when the aftermath has been carried. The water is first kept upon the ground for a fortnight or three weeks at a time; it is then let off, and the ground left dry for five or six days; and this process of alternately flooding and drying is continued until the end of January, care being taken to let the water off if a hard frost intervene. As the spring advances and the grasses shoot forth, the periods of watering are shortened, so that the flooding shall not last more than four or five days consecutively. In the southern counties of England, the meadows are ready for the reception of stock of all kinds in the middle of March; but more towards the north, where the grasses do not make such early progress, the flooding is generally continued through the whole month of May: after this it is discontinued for the season, and one or more crops of hay are produced. Flooding during the months of summer produces a rapid and rich vegetation; but it is by summer flooding, where it is practised, that the fatal

disease of rot is introduced, so that no sheep should ever enter the meadows which have been flooded during the summer months.

It is important that the water be removed from the land as rapidly as possible after the irrigation has been terminated. This removal of the surplus constitutes, in fact, the difference between water meadows and marshes, and too much attention cannot be paid to its attainment.

To shut out the waters from the conducting channels and the feeders when the flooding is suspended, or to raise them to such an extent as to cause them to flow over portions of the fields they could not reach naturally, hatches or sluices are used.

The most important of these is the hatch placed at the point where the main feeder branches into the stream. Without this the meadow might be inundated by any unexpected freshet: if the latter should occur when the crop is in a forward state, and if it be charged with matter in suspension, serious injury might arise to the crop. Similar hatches must be placed at the outfall, in order to exclude back-currents; but of course these are to be raised when flooding is in operation. It is also very useful to place hatches immediately below the points where the secondary conductors take their origin, and even occasionally to close the entrances of the feeders, either by a moveable dam or by merely placing a few pieces of turf across them.

Hitherto we have confined out observations upon the practice of irrigation to the agricultural region in which wheat is the staple produce of the zone. The same remarks apply to the region of the vine, for in it also the application of irrigation can only take place upon meadow lands. In fact, all waters appear to have a tendency to develop the leaves of plants rather than the fruits or grain; and in certain seasons of the year the vapour arising from moist land, so far from being advantageous, is positively injurious, especially when it is accompanied by sudden depressions of the temperature, such as occur in the later summer or the early autumn, when the fruit is ripening. In the vine district the rainy season occurs during the epoch of the growth of the plant when water is necessary for its development, and although unquestionably periods of drought occur during which the vines would be much benefited by a supply of water by artificial means, yet the occasions for such supply are so rare, as to render it manifestly absurd to undertake any extensive works, or to incur any great outlay for the purpose of effecting it. The climate of this region is, however, so dry, that in order to obtain grass or forage, it is indispensably necessary to form water meadows. Practically, the general principles stated as regulating these in the fourth agricultural district may be said to apply to those in the third.

With respect to the olive district, or the second, the necessity for watering lands intended to produce grass or to feed cattle is even greater than in the third and fourth, for the simple reason that the climate is hotter and drier. In this zone, however, irrigation has been from time immemorial applied to the gardens and pleasure-grounds in all positions to which it could be conveyed. The dry, clear, burning atmosphere has rendered artificial irrigation not only a necessity for the plants, but also a source of luxurious enjoyment to man. In such countries, wherever water can be applied, the vegetation assumes a degree of surpassing vigour under the combined action of heat and moisture. All beyond the line of irrigation is a mere barren desert, the more frightful from its contrast to the watered lands. The valleys of Damascus, Grenada, Hières, and others situated like them at the base of snow-capped mountains, are known as widely as truth or fiction can spread the tale of their marvellous beauty and fertility. However, confining ourselves to the mere practical question, the same general principles with respect to procuring water apply in this

zone which apply in the others, excepting that instead of being allowed to flow over the surface as in the case of water meadows, or of rice grounds, to be hereafter described, it is confined in regular channels, and produces its effects by infiltration through the light sandy soils prevailing in these regions. The remark made above as to the tendency of an excess of water to develop beyond its proper limits the leafy parts of plants, is even more true in the olive region than in the others, because the excessive heat of the climate increases the activity of the vegetative principle.

The main difference to be observed in the irrigation of this particular district from the system employed upon the water meadows of the two previously mentioned is that the former takes place principally by infiltration, whilst the latter acts by flooding the land, and consequently that the water-courses of the former are obliged to be kept constantly full. Such a process could only be successfully carried out upon the banks of a running stream, fed by what we may call perennial sources. Reservoirs could be of very little use in such positions, for the evident reason that they could not be made of sufficient capacity to allow of a regular and copious distribution during a lengthened period of drought. The character of the husbandry of such districts naturally takes its principal characteristics from these circumstances; and we find that meadow lands are rare, whilst gardens and orchards are common. In the latitudes comprised within the zone under consideration, the Indian corn appears to be the most adapted to supply the place of the grains produced more northerly.

The last of the regions to which irrigation is applied has been already described as that producing rice, which is cultivated to a considerable extent in Southern Europe, Asia, Africa, and America, below the 46th degree of latitude. The rice is essentially an aquatic plant, and requires to be constantly immersed in order to perfect its development. It appears that the quality of the land upon which it is raised is a matter of but little importance comparatively with that of the waters; and that the latter is by so much the better as it is charged with the greater quantity of extraneous matter. River and pond waters are the most advantageous; that of springs is the worst, because the purest and coldest, and it should not therefore be employed without being exposed in shallow reservoirs and mixed with animal manure. It is usually calculated that it requires about 1 foot cube of water per minute per acre to maintain a proper stream over rice land of a tolerably permeable nature.

In rice countries the cultivation is either permanent, or it performs part of a rotation. In the first case the land must be marshy, either from the want of outfall or from the springs rising in it. In the second case a species of artificial irrigation is requisite for every crop of rice to be raised.

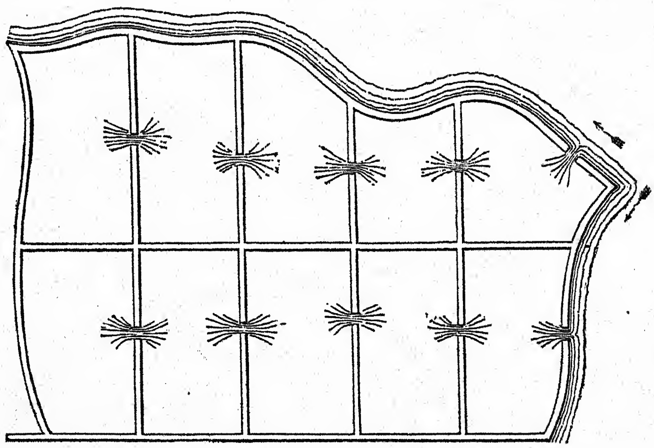
Whatever be the nature of the ground to be converted into rice lands, the first condition requisite is that the water be preserved continually in movement, and that all brought upon it be removed. A series of plane surfaces must thus be formed, so that no part be allowed to remain dry, and that the water be not allowed to stagnate in any part. The whole surface must therefore be levelled; and if it be too extensive for only one such surface, it may be divided into two or more, provided that each of them be nearly horizontal. The land is then to be ploughed, and the retaining banks are formed: of these there are two sorts,—firstly, the longitudinal ones, or those in the direction of the stream, which are intended to last as long as the field is laid down in rice; and secondly, the transverse ones, which intercept the direction of the current in an angular direction, so that when these banks are completed the rice-field is divided into a series of polygons. The size of these polygons is principally regulated by the difference of the levels of the planes of the respective parts of the field. In those which have much inclination they are numerous, in order to economize the labour of disposing them in horizontal planes. Moreover, their dimensions

are limited by the consideration that the larger they are, the greater probability there is that the wind may tear up the young plants when they only hold by a small root. The quantity of water disposable is also another consideration; and lastly, it must be borne in mind that the increased number of banks occupies a considerable surface of valuable land.

It is usual to make the banks about 6 inches above the ground on the upper side, and about 2 feet on the under; the width is never less than 6 inches at the crown, but as the top of the banks often serves for a road as well as for the particular object of their formation, this may vary indefinitely. They are made with the earth taken from the lower parts of the field.

When the banks are terminated, as indicated in the following diagram, the water is let into the first division, and allowed to rise about 5 inches all over the surface. Some openings are then made in the lower banks, and the water is successively let into all of them; so that the rice ground becomes converted, in fact, into a succession of small ponds, separated by the banks. This preliminary indication serves also to verify the levels of the surface,—all the portions left dry requiring to be lowered.

It does not enter into our province to describe more fully the mode of cultivating rice, further than to say that during the whole duration of its growth it is subject to irrigation by flooding, in a manner varying with the health of the plant, the degree of



Plan of Rice Grounds.

maturity, or the violence of the wind. It is therefore necessary to dispose the irrigation upon such principles as to be able to regulate its flow and to shut it off occasionally. After the crop has been carried, all the water is withdrawn, and the land is left exposed to the action of the atmosphere throughout the winter, and until the spring.

In many localities, both in England and abroad, a peculiar system of irrigation is practised, which consists in allowing waters highly charged with sediment to flow over the land and to deposit tranquilly the matters they contain. This system is known in our own country by the name of 'warping,' and it is principally employed upon the banks of the Humber: on the Continent it prevails to some extent in Holland and North Germany.

To resume, then, the different systems of irrigation, so far at least as they may be described in a general and comprehensive manner, they may be said to consist of—

1. Irrigation by level channels; in which the land is disposed so as to have a regular fall, and the water is conducted by means of level channels so as to distribute the water evenly over the surface in a thin uniform sheet.

2. Irrigation by feeders; in which the conductors lead the waters over the whole surface, but with less regularity, owing to the configuration of the soil requiring that their direction and inclination be modified.

3. Irrigation by stages; in which the ground is laid out in a succession of level planes, over which the water is consecutively distributed.

4. Irrigation by flooding; in which the water is let upon the land without any previous levelling of the surface, and in which great inequalities are allowed to exist in the depth of the water and its rate of flow.

5. Irrigation by infiltration; in which the water is allowed to permeate the land through the banks of the channels or the ponds in which it is confined.

6. Irrigation by rain-waters stored either in reservoirs at the gorges of valleys, or in channels so constructed upon a hill-side as to retain the winter-rains.

7. Irrigation for the purpose of retaining the matters in suspension in the waters.

Description of the Works required to carry out a system of Irrigation.

There are few branches of Engineering which require more skill than the one under consideration, especially in countries where water is valuable.

Of the different kinds of channels necessary to carry out a system of irrigation our attention may be confined to the following:

1. The leading channel, or conductor;
2. The secondary channels;
3. The feeders;
4. The discharging channels; and
5. The channels used for irrigation and navigation.

1. The leading channels are placed directly upon the banks of a stream or a river with which they communicate by means of works whose nature depends upon the character of the source and the quantity of land to be irrigated. They usually consist of two distinct parts, one lying between the point of junction and the first point to be irrigated; the second comprises the remaining part of the conductor with all its ramifications. The first part only serves as a leading channel, and inasmuch as it does not give off any water laterally, it retains a uniform depth and section. The second part, containing numerous branches, has a width varying successively according to the consumption of water by the subsidiary channels. Great care is requisite in settling the conditions of this main conductor, especially when the volume of the river is likely to be affected by droughts, in order to secure an efficient supply in such seasons.

2. The secondary channels bear the same relation to the main channel which this does to the river from which the supply is derived, and they should be formed upon the higher portions of the land to be irrigated. Their use is principally to distribute the waters over the remoter portions of the district.

3. The feeders are principally designed for the purpose of distributing the waters brought down by the channels, previously described, over the whole surface of the stages or planes.

4. The discharging channels are formed in the lower parts of the land to be irrigated, for the purpose of receiving the waters after they have flowed over the land, and to receive the quantity which may be in excess of that required for the particular object of the irrigation.

5. The channels, or perhaps, more correctly speaking, the canals, used simulta-

neously for irrigation and navigation, might be rendered a source of immense increase to the national wealth in many cases, by employing the water to the greatest possible extent; and, as it might also be made to serve as a motive power, it might thus be rendered triply productive. The essential difference between this class of canal and the ordinary navigable ones consists in the form of the locks, which, in addition to the usual chamber for the passage of the boats, have a sluice so arranged as to supply for the purposes of irrigation the quantity of water required without interfering with the movement of the navigation. The flow of the water over these sluices is sometimes employed also as a motive power, in which cases the tail bays require to be so placed as to allow the water to return into the main channel.

One of the most remarkable instances of the adaptation of an artificial water-course to the three uses of navigation, irrigation, and mill-work, is to be found in the canal of Pavia. In the upper portions the rate of flow is somewhat great, yet the up traffic from Milan to Pavia is effected at the rate of rather more than three leagues ($8\frac{1}{2}$ miles) per hour. The only defect which appears to exist in this canal arises from its having been formed in a stratum of permeable gravel, and that serious filtrations take place. Nevertheless, this canal, with an average volume of 245 to 250 feet cubic per second, serves to support a very active navigation, to irrigate a large district, and to drive numerous mills; whilst many natural rivers of much greater volume, owing to the irregularities of their beds, are not capable of supplying either of these sources of employment.

The first operation to be performed before commencing any large work of irrigation is to ascertain whether the land is near a water-course with considerable fall, and retaining in summer a sufficient discharge to insure the constant supply of the quantity required: secondly, to ascertain whether a sufficiently large surface of level, or nearly level, land exists, which, however, must combine such conditions of transverse section as to allow the water to be removed freely after it shall have performed its functions, without its being necessary to execute any very expensive works. The extent of the surface thus to be irrigated is indeed one of the most important considerations, because upon it will depend the dimensions to be given to the channel and the conditions of supply from the stream. The most favourable region for the establishment of irrigations appears to be near the feet of mountain chains, where the inclination, and the supply of water, are constant.

When these conditions are ascertained to be satisfactorily solved, it would be advisable, if possible, to take a contour map of the district, or at least to run as many longitudinal and transverse sections as possible. Upon the map so laid down the system is to be arranged,—observing that, in so far as the direction of the main channel is concerned, the shortest line is to be preferred, unless the expense of the earth-works bridges, maintenance, &c. be such as to justify a deviation. If, however, the source of supply be in a river whose summer level is exposed to variations, it may frequently happen that it would be desirable to give considerable length to the conductor, for the purpose of insuring a regular supply. As soon as the principal directions of the important works are thus settled, the ground must be levelled in the direction of the main axis, and a sufficient number of cross sections must be taken to allow of its being afterwards diverted, should such a course be found necessary.

Inclinations.—In stating, as we did above, that the inclination of the conductor and feeders should be about 1 in 500, it must be understood that the rule only holds good in the region then under notice. The question of inclination is really a very complicated one, and far removed from these simple appreciations.

For instance, in navigable canals the difference of level between the extreme points is for the most part overcome by locks; and as the lock-chambers, under any circum-

stances, are filled by the water flowing through the sluices under a heavy pressure, a fall between a set of locks would only impede the ascending navigation without producing any good result. A fall of from 10 to 12 in 10,000 is then the extreme of all that should be admitted in such works. In the main conductors for a system of irrigation this rule requires to be modified, for as the land must receive a certain definite quantity, the fall and dimensions of the canal must be modified accordingly. The maintenance of the banks of the canal is most favourably effected when the rate of flow is moderate ; and, as a further general remark, we may observe, that if the water be intended to be used as a motive power, there exists an additional reason for rendering the fall as slight as possible between separate portions of the course, and for overcoming the difference between the extreme points by means of mill-dams. There is, however, a limit in this direction, beyond which it becomes dangerous to diminish the rate of inclination ; for should the river from which the supply is derived bring down much matter in suspension, a canal with a feeble inclination would be exposed to become silted up very rapidly. All these conditions again may be modified by the nature of the strata traversed ; for if they should be of a description to retard the flow of the water, they may frequently require that the inclination be augmented.

In most countries certain rules prevail in these matters, which appear to be founded upon local experience without much reference to logical principles. Vitruvius recommends that in water-courses an inclination of about 55 in 10,000 be given. Scamozzi and Alberti indicate one-half the above as being the best ; whilst in the sixteenth and seventeenth centuries the hydraulic engineers of Lombardy adopted inclinations varying from $\frac{1}{1500}$ to $\frac{1}{2000}$: at the present day the inclinations given in that country are even less than those last cited, for the waters are usually sufficiently clear to obviate any danger upon the score of the silting up of the channels. In mountainous countries, again, we find that the inclinations are greater than in plains, because in such cases there is less occasion to economise the water.

The following are the inclinations of some of the principal canals, either for irrigation, or for navigation combined with irrigation, in France and Italy :

In the upper valleys of the Alps, Switzerland, Savoy, Tyrol, the Dauphiné, and in the valleys of the Pyrenees	$\frac{1}{500}$
Average inclination in the Isère, Drome, &c.	$\frac{1}{937}$
Canal des Alpines (ancient southern branch)	$\frac{1}{500}$
Do. do. (modern northern branch)	$\frac{1}{2500}$
Do. de Marseille, modern, varying from	$\frac{1}{1000}$ to $\frac{1}{2174}$ and $\frac{1}{3333}$
Canale di Caluso, in the province of Ivrée, in Piedmont	$\frac{1}{543}$
Do. of the Sessia, left bank	$\frac{1}{1250}$
Do. of the Ticino, right bank	$\frac{1}{1388}$
Modern canals executed by individuals	$\frac{1}{1000}$

Canals for Irrigation and Navigation.

Naviglio Grande, Milan	No. 1.	$\frac{1}{888}$
Do. do. do.	No. 2.	$\frac{1}{1470}$
Do. do. do.	No. 3.	$\frac{1}{1818}$
Canale di Berguado		$\frac{1}{5883}$
Do. di Pavia		$\frac{1}{3333}$
Do. della Martesana		$\frac{1}{2340}$
Do. della Muzza		$\frac{1}{666}$
Private Canals recently executed, from		$\frac{1}{1805}$ to $\frac{1}{3800}$

It appears from this, that in mountainous countries, hardly any limit can be said

to exist for the inclination of the irrigation channels; but when it exceeds $\frac{1}{333}$ the fall must be regulated by a series of cascades or dams, for there are very few soils able to resist the denuding action of currents running with the velocity of such streams. The inclination which appears to be the most adapted to the waters of La Provence, containing much matter in suspension, ranges between $\frac{6}{10000}$ and $\frac{9}{10000}$. In Italy, on the other hand, where the waters are comparatively clear, the inclination given to the modern works of this nature is considerably less than that formerly judged to be indispensable.

We may assume in practice, that in mountainous districts the inclination should be about $\frac{1}{500}$; that in plains, the channels exclusively devoted to the purposes of irrigation should be from $\frac{1}{1666}$ to $\frac{1}{3600}$, whilst if they be designed for navigation, as well as for irrigation, the limits must range from about $\frac{1}{3333}$ to $\frac{1}{6666}$. In the latter description of canals, the determining reason for the rate of inclination will often be found in the direction of the traffic. If it be in the direction of the stream, there may be no objection to adopting even so great an inclination as $\frac{1}{2500}$, whilst if it be upwards or against the stream, the rate of fall must never exceed from $\frac{1}{6666}$ to $\frac{1}{4000}$ at the utmost. Even the more favourable of these is, however, of a nature to cause an obstruction to the navigation.

The subsidiary channels and feeders may have rates of inclination greater than those cited above, because, their object being to distribute the water over the ground, it is necessary that they be arranged so as to allow of its flowing off as rapidly as would be consistent with the condition of not furrowing the subsoil. In the operation of 'warping,' however, the leading channels must be made with a very rapid inclination. In this case it is desirable to lead the waters containing matter in suspension upon low-lands, so that the deposit may take place upon them.

Section of Feeder.—From the considerations alluded to in the former part of this article, it must be evident that the dimensions of the feeders must be regulated by an infinite variety of circumstances, either arising from the general inclination of the ground, or from the nature of the soil to be irrigated. Stated in general terms, however, the problem to be solved may be thus expressed—"Given the quantity of water to be supplied, and the rate of inclination, to determine the section."

The French and Italian Engineers have invariably adopted Eytelwein's formula, to ascertain this section, which is as follows:

$$\text{D cos. } \phi = 0\cdot00717\,\frac{u^2}{2g} + 0\cdot000024\,u\,;$$

D representing the product of the section of the water-course by the wet contour;
cos. ϕ, the cosine of the angle formed by the inclination of the bed from the vertical;
g, the accelerating force of gravity;
u, the mean velocity.

This formula will suffice for almost all the cases which can arise in practice; for although in it the width only is sought, yet as in most cases the height is given, the width is in fact the only unknown element. We may in some cases substitute the expression $\text{D} = \frac{h\,x}{x + 2\,h^2}$, in which h = the height,* and x, the width sought; and $u = \frac{\text{Q}}{h\,x}$, in which Q = the volume to be discharged.

* It is to be observed, that in all canals intended for the double purpose of irrigation and navigation, the depth is necessarily fixed by the dimensions of the boats employed.

The formula becomes after these substitutions, and, as in the preceding case, supposing the movement to be uniform,

$$\text{Cos. } \phi \; h\, x^3 - \frac{b\,Q}{h^2} x^2 - \left(\frac{a\,Q^2}{2\,g\,h^2} + \frac{16\,b\,Q}{h}\right) x - \frac{a\,Q^2}{g\,h} - 4\,b\,Q = 0,$$

$a = 0{\cdot}00717$, and $b = 0{\cdot}000024$: these are introduced to avoid confusion in writing the equation.

A much more convenient formula is, however, given by Tadini, and adopted by Nadault de Buffon. It is,

$$0{\cdot}0004\ Q^2 = \cos.\ \phi\ l^2\ h^3;\ \text{ or } Q = 50\ l\ h\ \sqrt{h \cos.\ \phi}.$$

In this, the inclination is represented, as before, by cos. ϕ ; l = the mean width of the channel ; h = the height ; and Q = the quantity to be discharged per second.

In arranging the dimensions of the feeder, however, it must not be forgotten, that there are numerous causes in operation by which the effective quantity of water distributed over the land is diminished : amongst the principal may be cited the loss arising from evaporation and filtration, and that arising from the defective state of the sluices or other works. In the Milanese, where the canals are formed in an illuvial soil, resting upon beds of sand and gravel, and where, from the warmth of the climate, the evaporation must be great, the loss from these causes has been ascertained to be about 15 per cent. (See article 'River and Inland Navigation.')

In warm climates an additional allowance is required to be made to compensate for the extraordinary rapidity with which the aquatic plants increase. Indeed, in Italy, notwithstanding the legal obligation to cut them twice in the season, it is often found that in the latter parts of the summer, at least half the section of the canal is occupied by them. The peculiar growth of the fresh-water algæ in long festoons also appears to influence the flow of the water to a greater extent than the space occupied would account for. In Lombardy the augmentation of the section required to obviate this inconvenience is sometimes as much as from $\frac{1}{25}$ to $\frac{1}{2}$ of the normal section ; but, of course, no absolute rule can be assigned.

In England it is rarely necessary to measure the quantity of water distributed to the different landowners, but in warmer climates this becomes a matter of vital importance in the economical results of irrigation. We shall have occasion to revert to this question of gauges, but in the mean time it may suffice to observe that their establishment requires that the minimum height of the channel be fixed at three feet. In practice, the Italian engineers make the mean widths of the canals one and a half times the depth, unless there be some exceptional conditions in the particular case.

The land springs met with in forming the different channels may very frequently become of great importance, and they should therefore be diverted to the purposes of irrigation on all occasions upon which they may be found to be of a temperature and of a composition suitable for the purpose.

The rules above given for the calculation of the dimensions of the feeders are only applicable for those portions of the length within which no distribution takes place : as the smaller distributing channels draw off the water, it must be evident that the dimensions of the main channel should decrease.

When the main channel is designed for the purposes of navigation conjointly with irrigation, the section must be modified so as to insure the volume of water necessary for the two services : in such cases it is indispensable to provide a sufficient quantity to compensate for the lockage, in addition to that distributed upon the land, and this quantity will be ascertained in the manner employed in similar calculations for canals. The Naviglio Grande, and the Martesana, in the Milanese, present a peculiar arrangement, which, however, may often recur, viz. the canals terminate in a basin which

receives the lockage water of the upper reaches, and the distribution for irrigation and for mills takes place from the basin. Evidently, in these cases, the section of the irrigation channel is to be calculated upon the principles already described.

The discharging channels perform a part in the irrigation of a district precisely the reverse to that of the feeders, and their sections must therefore be also precisely in a different proportion.

Other Conditions.—In setting out the main channels, it is important to make the radius of curvature of the changes of direction as large as possible, to avoid any interference with the discharge, or any destructive action upon the banks. It should never be less than from 100 to 150 yards in the most unfavourable positions.

The height of the banks above the water-line need not necessarily be more than from six to eight inches when the supply is constant. The rapid growth of aquatic plants, however, renders it advisable to augment this dimension to about from 16 to 18 inches. When the canal is also to be navigated, it is advisable to increase this height, in order to guard against the wave of displacement occasioned by the boat.

In fixing the slope of the banks, the twofold object of economy in the first instance, and of the minimum outlay for maintenance in the second, is to be observed. When the channel is cut in a hard retentive rock, it must be evident that the proper section is one approaching a rectangle. In any other kind of soil the angle of inclination of the banks must vary with the degree of its powers of resistance.

The reader is referred to the article upon 'River and Inland Navigation' for the other details respecting the earth-works connected with canals, which apply equally to those for the purpose of irrigation as for navigation.

It is advisable to form a pathway on the two sides of the main channel, to allow of its being visited, and of the deposition of the mud, &c. withdrawn from the bed at the regular periods of cleansing. These pathways should be made with a width of from 2 to 3 feet. The operation of cleansing, to which we have alluded, is not one of great importance in England,—at least comparatively; but in Southern Europe it requires to be executed at least twice a year, and during the whole period of its execution it has been found advisable to run off all the water from the channels. It therefore becomes necessary, in similar positions, to construct such lock-gates or sluices as to allow of diverting the stream.

Reservoirs.—When the flood-waters stored in reservoirs are to be employed for irrigation, the determination of the dimension of the sluices and the form of the channel, require considerable care. The discharge by any opening is liable to so much uncertainty, even when the conditions of the head remain constant, that very little reliance can be placed upon the accuracy of the formulæ universally adopted to ascertain it. As the level of the water in a reservoir must necessarily vary, an additional and very serious complication is introduced. Without, therefore, pretending to lay down any absolute rule, it appears that the wisest course to adopt would be to calculate the dimensions of the opening, upon the supposition of the least possible head, because by merely lowering the sluice the opening can be contracted. In many cases the self-acting sluices used upon the Greenock Water-works might be advantageously employed.

In calculating the quantity discharged by an orifice, the usual formula is given by Navier as follows :—

$$Q = m S \sqrt{2 g H};$$

in which S = the area of orifice; Q = the quantity; m = the coefficient of contraction; g = the velocity impressed upon a falling body at the end of the first second of its fall; H = the height of head upon the centre of the opening. The value of m,

for a single sluice, may be taken at 0·625 if near the bottom; when there are two sluices near one another, m becomes $= 0·555$. The disturbing effect of two sluices is perceptible when they are even so much as 10 feet apart.

Should the water in the reservoir arrive with any velocity at the opening, the formula becomes

$$Q = m\,S\,\sqrt{2\,g\,H + u^2};$$

in which $u =$ the velocity of the water leaving the reservoir.

If the outer opening of the sluice be submerged, it becomes

$$Q = m\,S\,\sqrt{2\,g\,(H - h)};$$

in which $h =$ the head upon the outside, supposing the water to have no initial velocity: of course, should this exist, it must be taken into account as before.

The construction of the reservoirs themselves has been already alluded to, and indeed it is in all cases precisely analogous to that of canal reservoirs described in the article upon 'River and Inland Navigation.'

In addition to the formulæ previously given for the purpose of ascertaining the dimensions of the works, the following may be found convenient in practice. For regular channels, in which the inclination, sectional area, and wet contour can be easily ascertained, the volume may be found by the aid of the formula.

$$Q = S\left(\sqrt{2736\,\frac{\cos.\,\phi.\,S}{c}} - 0·0332\right)$$

in which the same notation is observed as before, and $c =$ the wet contour in yards. In small streams, the most accurate mode of gauging appears to be by creating a reach of still water, and allowing it to flow over a notch-board as soon as the velocity has been checked. The formula for calculating the quantity becomes

$$Q = m\,L\,H\,\sqrt{2\,g\,H},$$

in which $L =$ the length of the notch; $H =$ the height of the mean level of the reservoir above the bottom of the notch; m is a coefficient which is usually taken at 0·405.

To ascertain the velocity of a stream many systems have been employed, but the most satisfactory appears to be the hydrometric mill of Wattmann, represented in most works on hydraulics. The mean velocity is calculated from the partial velocities, thus obtained by the formulæ given in page 259, article 'River Navigation.'

Gauges.—In England, the supply of water, as said before, is usually so copious in all the valleys where irrigation is carried into effect, that the quantity distributed to any proportion of the land ceases to be worthy of calculation. In warmer climates, or when the preliminary expense of procuring the water has been considerable, the economical value becomes, however, so much enhanced that it is a matter of primary importance to ascertain the quantity distributed to the respective recipients. There are, indeed, few countries so favourably situated as to dispense with these means of regulating the distribution; and it may be taken as an axiom, that in dry climates no distribution of irrigation waters should take place without the intervention of a complete system of gauging. The question has been most carefully studied by the Engineers of Northern Italy; some of the gauges employed by them are described below, and by Colonel Baird Smith in his work on 'Italian Irrigation.'

The investigations of the Italian Engineers connected with the subject of gauges have led to the establishment of some laws of hydrodynamics of the highest interest. Thus, it was ascertained that in a vase divided into two portions by a diaphragm, susceptible of being moved vertically and with a discharging orifice on one side, a

constant difference of level existed; and that this difference was greater in proportion as the opening of the diaphragm was less, compared to that of the orifice (see fig. 9).

If, instead of preserving in the vase a uniform level, it were allowed to vary in either direction, the corresponding variations of the two sides of the diaphragm continued to be always proportional with the respective differences of level first established. That is to say, if the relative heights were originally as 3 to 1, a rise of 30 inches in the first vase would only cause a rise of 10 inches in the second.

This principle is not modified by the introduction of two or more diaphragms, as in fig. 10. The same ratio is observed between the variations of level and the primitive heights of the water in the first and last compartment, notwithstanding the addition of any number of diaphragms, which, in fact, should only count for one.

Fig. 9.

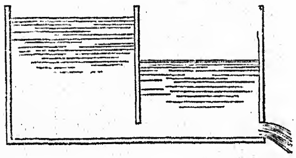
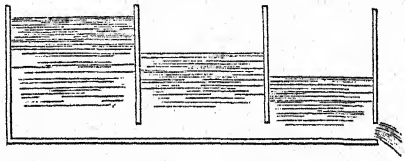
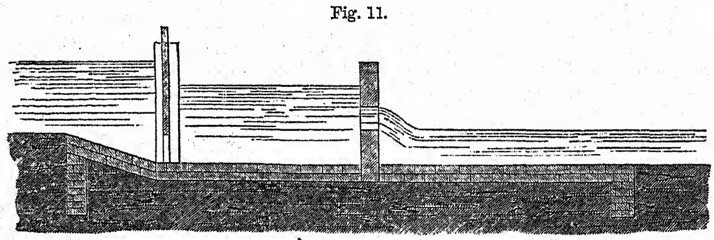


Fig. 10.



Now, if we suppose that the first portion of the reservoir be a canal and the diaphragm a sluice, and the distributing channel perform the functions of the orifice, it may easily be perceived that it is possible, by means of this sluice, to maintain the

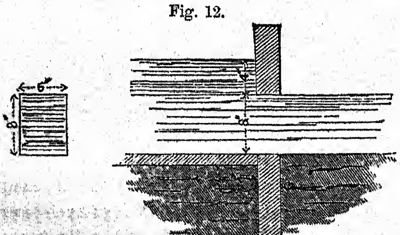
Fig. 11.



constant head above the orifice which is necessary to insure the regularity of the flow. By simply raising or depressing it the requisite conditions are obtained, and it would be possible so to construct the sluice that it should be self-regulating. At any rate, inasmuch as it is found that the level of the upper reservoir may vary considerably without seriously affecting that of the intermediate one, for most practical purposes, a gauge established upon the above principles, with a sluice moved by hand, may be considered as sufficiently accurate.

The gauge used in the Milanese canals is the most in accordance with the principles above stated, and as it were much to be desired that its use should be extended in all cases where irrigation is employed, a description of it is subjoined.

Fig. 12.



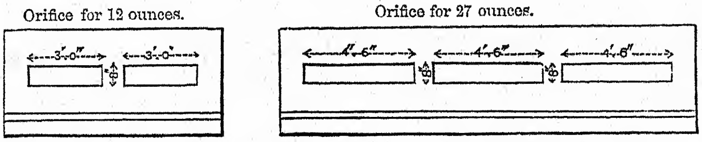
The unity adopted in the measurement of water is called an ounce, '*l'oncia d'acqua*,' and is the quantity which flows through a rectangular orifice 8 inches high and 6 inches wide, under a constant pressure of 4 inches above the orifice, as in fig. 12.

When t is desired to distribute a larger quantity than a single ounce, the width

only is modified : all the other conditions are carefully maintained, so that the head never exceeds 4 inches. The orifices of discharge are formed of stone, which is selected of the hardest nature that can be procured ; occasionally also the margin is formed of wrought or cast iron. They are cut square, without any bevel, or the addition of any funnel capable of facilitating the discharge. There are no prescriptions with respect to the thickness, which depends necessarily upon the length of the orifice ; and this latter consideration also has led to the custom of not making the orifices larger than for six ounces each ; when a greater quantity of water is to be supplied, the number of the orifices alone is augmented.

Fig. 13.

Orifice for 12 ounces. Orifice for 27 ounces.



The conductor is formed upon the banks of the canal by means of wing-walls of masonry, and the sill is usually placed at the bottom line. If the ground be susceptible of being carried away, the portion exposed to the wash of the water is to be paved. The opening *a b*, fig. 15, of the conductor is made equal in width to the orifice of discharge, *p q*, but the height is not limited.

Fig. 14.

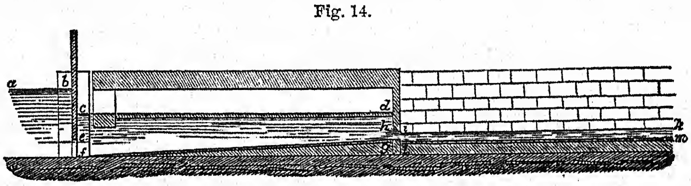
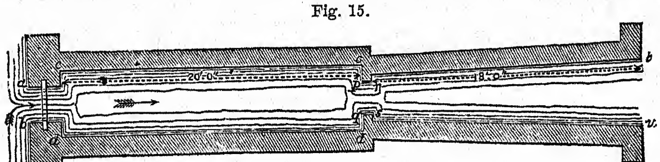


Fig. 15.



In such canals as have a constant flow, it is usual to place a stop upon the sluice, but in those exposed to variations of volume the stop would be more likely to be prejudicial than to be of use.

The rectangular space *c c*, *d d*, fig. 15, is made about 20 feet in length, and 10 inches on each side wider than the orifice. The bottom is laid with an incline of 16 inches in the length, rising towards the orifice, *g h*. At the level *c d* (in fig. 14) is a flooring, placed for the double purpose of preventing the water from rising beyond the prescribed height and to control any movement or agitation on its surface. The entry of this covered portion of the gauge is formed by a stone lintel, the under-side of which is exactly level with the top of the orifice, and consequently 4 inches below the surface of the water. As the height of the orifice is always 8 inches, and the inclined plane 16 inches, the under-side of this lintel is consequently 2 feet above the sill of the sluice. A small space is left between the sluice and the covered chamber, for the purpose of verifying whether the requisite head of water exists upon the orifice.

Immediately beyond the orifice is the tail chamber, which is made 4 inches on each side wider than the opening; its length is usually 18 feet, and at the further extremity its width is made 6 inches on each side wider than at the commencement; or, in all, it is 20 inches wider than the orifice. A small drip of 2 inches is formed at the commencement of the tail bay, and an inclination of 2 inches is given from this to the extremity, *t u* or *k m*, figs. 14 and 15.

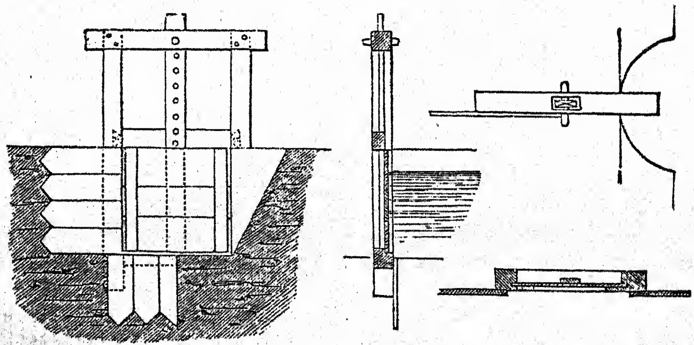
Gauges of this description require a minimum difference of 8 inches between the level of the water in the canal and the constant level of the water in the covered chamber. They can, therefore, only be fixed upon canals with a depth of about 3 feet. In execution, the longitudinal dimensions are not rigorously enforced; but the width, and nearly always the inclinations and the relative heights of the openings, are executed in exact accordance with those above described.

The gauge we are considering, although unquestionably the most perfect hitherto employed, is still far from fulfilling all the conditions theoretically required. Thus, a notable difference exists in the quantity of water discharged by large or small orifices, to the extent that with six orifices of one ounce each the discharge would only be, when compared to that from a single orifice of six ounces, as 222 to 282. In warm countries the difference would be serious; and the Piedmontese and Milanese engineers have lately tried to obviate it by prescribing that no orifice be made larger than six ounces, or 3 feet in width. The difference in the discharge is easily explained by the difference in the proportion the perimeter bears to the sectional area, which evidently is less when the orifice is large than when it is small.

Sluices and Overflows.—The conditions to be observed in the construction of these works are, that they should afford an effectual guarantee against floods, or any sudden rise of the water in the channel. They should be as permanently constructed as possible, and able to be worked easily.

In most countries the dimensions of the bottom sluices are arbitrary, and they vary from 5 to 7 feet in width in many instances. They are worked either by wheel and pinion, by screws, or by long levers working in holes formed on the upright bar in the centre of the sluice. In the Milanese provinces, however, the dimensions are uniform, and when the height of water does not exceed from 5 to 6 feet, the width is never more than 1 foot 10½ inches. Should the depth be greater, the upper portion, for a height of from 1 foot to 1 foot 6 inches, is made separately moveable by

Fig. 16.



smeans of two small posts at the back. In this case the upper part of the sluice serves as an overflow, and frequently suffices to maintain the water within its

banks; but in countries like the neighbourhood of Milan, the use of water is so continual, that it rarely happens that this mere superficial overflow can suffice.

Fig. 17.

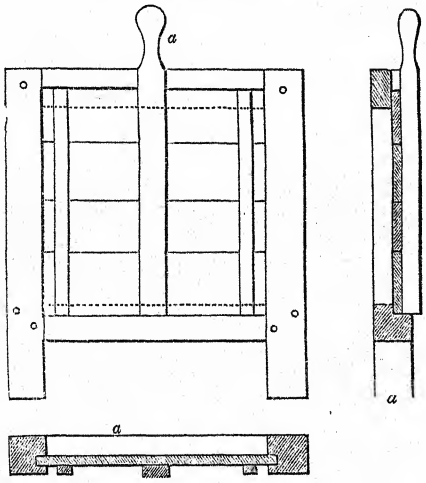
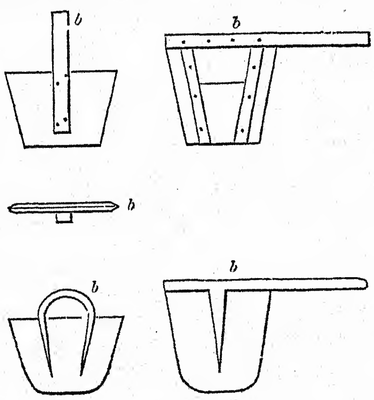


Fig. 18.—Details of the large, small, and tumbling sluices worked by hand.



The sluices used in the Milanese provinces have an upright rod upon which notches are formed; and the guardian of the canal, or the water-bailiff, carries a short lever by means of which he raises up the sluice. Two or three seconds suffice to procure an opening which, with the head of water existing upon the upper side, produces a very rapid effect upon the water. (See fig. 20.)

With respect to the fixed overflows little need be said, because they differ in no respect from those established upon canals or the leading channels of a mill. It is, however, of the utmost importance that such works should be established if the source from which the feeder derive its supply be exposed to sudden variations in its volume.

Fig. 19.

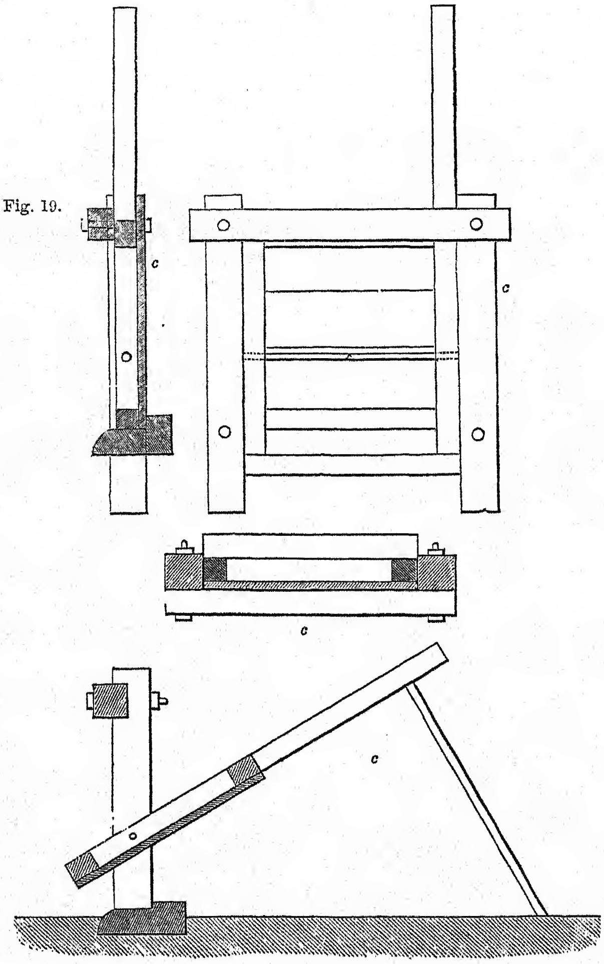
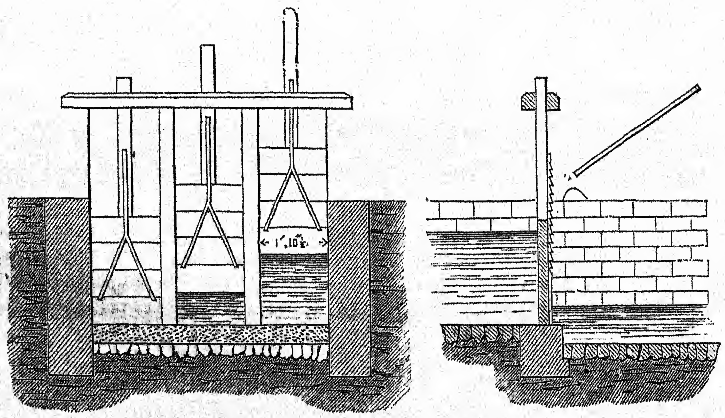


Fig. 20.



Junctions with the main stream.—Unless there exist some very exceptional circumstances owing to the torrential nature of the stream, and particularly to the instability of the bed, the system usually preferred is to establish a dam across the current of considerable length, and placed in an oblique direction. It appears advisable, under any circumstances, to provide overflows of sufficient dimensions to carry off any flood likely to come down from the up-lands, in order to protect the channel formed for the purposes of irrigation. In the junctions constructed of late years it is also customary to place lock-gates or sluices, with the double object of regulating the quantity of water to be introduced, and of isolating the canal from the river during the annual repairs or operations for cleansing the bed.

The nature of the dam must depend upon local circumstances to such an extent that it is impossible to lay down any absolute or invariable rules. In these matters local experience will be the best guide; but whether the dam be composed of stone, of earth, of wood frame-work, or of fascines, the foundations, and the means of protecting them from the tendency to overthrow exerted by the stream, must be the most important objects to be considered. The oblique direction of the dams is to be accounted for by the necessity for obviating the destructive action of the current as economically as possible: for firstly, the shock of the water upon them must be to a great extent lessened; and, moreover, as the stream of water flowing over the crown must be less than if the whole volume fell over a dam placed directly across the stream, not only in its height but in its action, the foundations are less exposed to be undermined. If these motives did not exist there would be an evident advantage in making the dam perpendicular to the direction of the stream.

Bridges, Aqueducts and Syphons.—These works do not present any distinctive characteristics from those connected with navigable canals, excepting, perhaps, that in order to retain all the velocity of the water, the courses require to be made as straight as possible: the aqueducts therefore are more often executed on the skew than in canals. It may be taken as a rule, that bridges upon irrigation works should be executed in masonry rather than in wood, to avoid the repairs inseparable from the latter, especially in such positions.

With respect to syphons, the principal remark to be made is, that every angle or sudden interruption in the line of flow is likely to become a source of diminished velocity. Wherever possible, then, cast-iron pipes should be used, because they admit of the curves being made more easy, and at the same time this material resists more effectually the outward thrust of the water. To combat the latter effort it is often necessary to bind together the whole of the materials in the arch or syphon. All these works require to be executed with the best materials and in the most permanent manner.

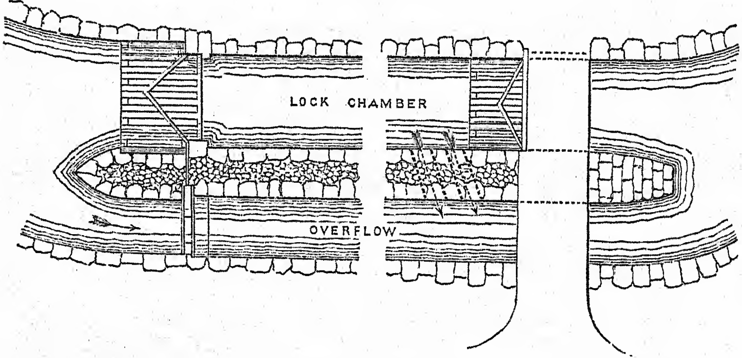
Locks.—The locks constructed upon canals for the double purpose of navigation and of irrigation, present, as we before said, this peculiarity, that they require, in the first place, a chamber of the dimensions necessary for the passage of the boats; and in the second, a passage for the purpose of transmitting from the upper to the lower chamber the volume of water only. The former do not require any details of execution different from locks upon ordinary canals; the latter are usually regulated by means of sluices.

Generally speaking, the fall in these positions is sufficient to justify the establishment of water-mills, either for the purpose of raising the water to a higher level, so as to irrigate a wider district, or of performing many of the common farming operations, such as threshing, winnowing, &c. In all cases, therefore, where the full benefit of the water power is obtained, such works are established. An example from the canal of Pavia is subjoined, although in this case the fall is not used. By the

difference in the level of the water in the two chambers, and by means of some conduits placed in the side walls, the boats are enabled to descend very quickly.

The principal precaution to be observed in the construction of these conduits is, that their foundations be made sufficiently strong to be able to resist the current of water passing through them: their direction, whether at right angles or obliquely, to the stream, is a matter of no importance, unless the water they discharge be likely to interfere with the tail waters of the mill which may be erected near the lock. Gates hung upon a vertical axis, a little beyond the centre, and working in a frame with a rebate partly upon the upper, partly upon the lower side, appear to be the readiest means of closing these sluices.

Fig. 21.



In Lombardy, water is often obtained from wells for the purposes of irrigation. The reader is referred to the different authors who have treated upon this subject for the principles which must guide the operations for seeking the springs. When these are found at a convenient level, their distribution must take place in the same manner as before.

Should the level of the water in such wells, or in any natural source from which it is proposed to be derived, be considerably below that of the land to be irrigated, it becomes necessary to employ artificial means of raising it, or to create some method of securing the supply by means of reservoirs. Unquestionably the latter mode would be the most economical, did local circumstances favour their construction, but the configuration of country required is not always to be met with, especially in positions where the soil is most adapted for irrigation. To construct a reservoir economically it is necessary that a valley should exist, the mouth of which is nearly closed by projecting spurs of the hills. The subsoil must also be of a homogeneous, retentive character, and of a nature to allow the construction of the works connected with the dams, without any fear of their being undermined. These conditions are rarely to be met with, excepting in mountainous districts, and these are ordinarily at too great distances from the alluvial plains most fitted for the cultivation of grass, or leguminous plants, which are those most likely to be benefited by the application of water. If, however, it be possible to form a reservoir, even at considerable expense, that course should be adopted; because, firstly, that mode of procuring water obviates the necessity for constantly providing a motive power, and secondly, the water by being stored becomes more fitted for agricultural purposes. Indeed, as the supplies are derived entirely from rain falling upon the up-lands, the temperature of the water must more nearly approach that of the ground, and they must also contain the soluble chemical matters the latter may be able to impart. The dangers from

infiltration and evaporation attending the use of reservoirs have been already mentioned in the article on Inland Navigation, sect. "canals."

The formation of an irrigation canal, deriving its supplies from a river at a high point in its course, affords the means of applying the process upon the largest and most efficient scale, and must necessarily be the method most commonly adopted. For the upper lands, situated above the flow of the stream, the choice of the mode of raising the water must be regulated by local circumstances, not only of position, but of use. Thus, if the lands to be irrigated be devoted to market-gardening, animal power may be employed, and the simplest machines are to be preferred, because the cheapness of their first establishment, and the facility with which they can be repaired, place them within the reach of everybody.

For agricultural operations on a large scale, however, it often becomes necessary to resort to more powerful means of action, and the modes which are usually adopted are to employ the motive power either of water, of wind, or of steam.

If a sufficient fall, possessing the requisite conditions of regularity, exist, it will usually be found preferable to employ it, because the power would thus be obtained at a far less cost than if steam be used, and it would also be more regular in its effect than that produced by a wind-mill. As to the particular system of wheel to be employed, that must depend upon so many considerations, that it would be useless to attempt to lay down any general rule. The simplest are the best, for in the country the class of workmen able to repair the more complicated ones are rare, and it is certainly desirable that no machines should be used upon a farm but such as the village smith or carpenter could repair.

If the water-fall be small, the quantity raised must be also limited, and it may perhaps, under such circumstances, be necessary to combine a system of reservoirs with the other machinery, in order to store the water raised during the intervals of its being employed upon the land. If the fall be great, there must necessarily exist a considerable inclination of the bed of the river, and it would usually be preferable to make a branch canal at a higher level. Such powerful water-falls are rarely neglected, however, by manufacturers, and as they are more valuable for such purposes than for irrigation, it is by no means desirable that they should be used for the latter. It appears probable that hanging wheels upon boats fixed in the stream, or turbines, might occasionally be used with advantage.

Wind affords a source of power such as we may call gratuitous, but unfortunately it cannot be controlled, so that if it be applied for raising water for irrigation, there might be an abundant supply when not wanted, and none when there was the greatest necessity for it. If this motive power be resorted to, it becomes indispensable to construct large reservoirs ; but the expense of establishing and maintaining these, and of eeping the engine and machinery in repair, would exceed that of establishing and maintaining a system of reservoirs for storing rain water. In drainage operations these remarks do not apply, because the precise period at which the water is removed is but of little importance, and the action of the wind possesses sufficient regularity r this purpose, if the whole year be considered.

Steam engines are far too expensive to allow of their being employed, unless in such neighbourhoods as furnish the skilled labour their repairs must require, and unless the district to be irrigated be of sufficient importance to warrant the constant employment of a staff of workmen able to keep the machinery in an efficient state. The price of coals must also materially affect the question as to the application of this mode of raising water. The construction of reservoirs appears to be advisable in this case as in others, and to give rise to considerable economy, by rendering the work more constant, and thus enabling smaller engines to perform it.

When the source of power shall have been decided upon, there still remains the equally important question of the description of machinery to be employed in actually lifting the water.

SECTION II.—MACHINES FOR RAISING WATER.

The machines employed for the purpose of raising water for irrigation have hitherto been entirely confined to the following:

1. Pumps; 2. Archimedean Screw; 3. Machines with buckets, such as the noria, chain-pumps, &c.; 4. Wheels, either with buckets, or water-ways upon the frame itself; 5. Miscellaneous Machines.

1. *Pumps.*

When the quantity of water to be raised, and the elevation to which it is desired to raise it, are considerable, pumps are the machines at present considered to be the most economical.

A pump consists of a hollow cylinder, in which the piston moves alternately up and down, in two pipes, one above the piston, called the ascending pipe, and the other below, called the suction-pipe; and lastly, in a series of clacks.

The cylinder is hollow and circular in the greater number of instances, although quadrangular and polygonal pumps are occasionally used. It may be of wood or of metal; but the former material wears away too rapidly for works destined to be used for any length of time. It is, therefore, almost exclusively confined to agricultural purposes; cast iron, or brass, are more generally employed; but of whatever material the cylinder be made, it is essential that it should be perfectly true in its bore.

The power of a pump depends upon the interior diameter of the cylinder. It is considered small if this diameter be less than 4 to 5 inches; large when it exceeds 1 foot; the largest rarely exceeds 1 foot 4 inches, although occasionally the diameter is made 2 feet.

The length of the cylinder should but little exceed that of the stroke of the piston. The piston itself is the most important part of the machinery of a pump, and the one which has received the greatest number of modifications. If the piston raise the water during its ascent or descent only, the action is said to be *single*; if, on the contrary, it raise the water by both motions, the action is said to be *double*. When the piston works entirely above the level of the water in the well, the pump is called a *suction*-pump; a *rising*-pump is one by which water is lifted during the up-stroke of the piston; a *forcing*-pump is one by which it is lifted during the down-stroke. A *double-acting* pump is, therefore, both a rising and a forcing pump.

The piston is very frequently nothing more than a piece of wood, usually of hornbeam, which it is advisable to soak for some time in boiling oil; but for pumps of any importance it should be either of iron or of brass. The packing is sometimes of leather soaked in oil or tallow, and is fastened to the top of the wood in ordinary pumps; the diameter of this packing is rather greater than that of the piston itself, so that it forms a species of cup upon the top with a flexible contour, which is pressed against the sides of the cylinder by the weight of the water.

At other times the packing consists of two fillets of leather, kept in their positions at the top and bottom of the piston by two brass rings; the space between these fillets is packed with hempen cord, well tallowed, which projects a little, and works against the inner bore of the cylinder.

Cast-iron pistons are often used, with an exterior packing of hemp or of leather. A projection at the bottom and a ring at the top, susceptible of being moved by a screw, press this packing against the inner bore. But the difficulty of turning the cylinders perfectly true, and the imperfections of the pistons described, have fre-

quently led to the adoption of the *plunger*-pump. This consists of a piston of brass, solid or hollow, of a length a little in excess of its stroke, and of a diameter about

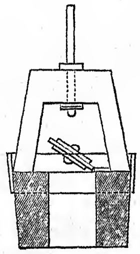


Fig. 1.

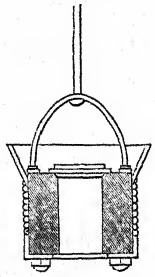


Fig. 2.

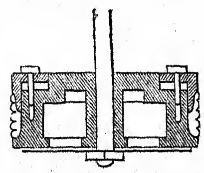


Fig. 3.

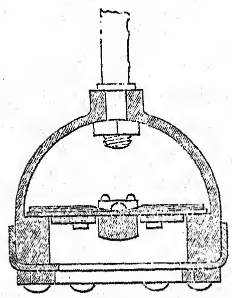


Fig. 4.

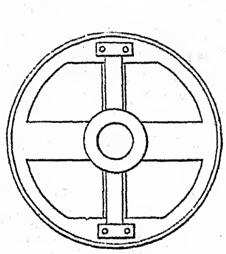


Fig. 5.

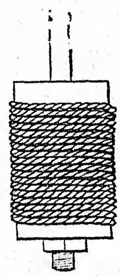
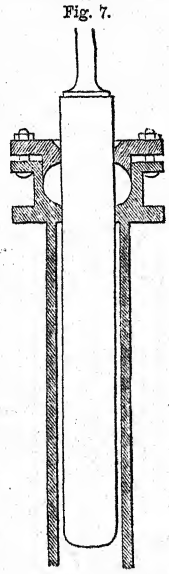


Fig. 6.

$\frac{1}{2}$ or $\frac{3}{4}$ of an inch less than that of the cylinder, also of brass. The piston works in a stuffing-box, and in descending it displaces a certain quantity of water, which is forced by this means into the ascending pipe, and when the piston rises it forms a vacuum.

Fig. 7.

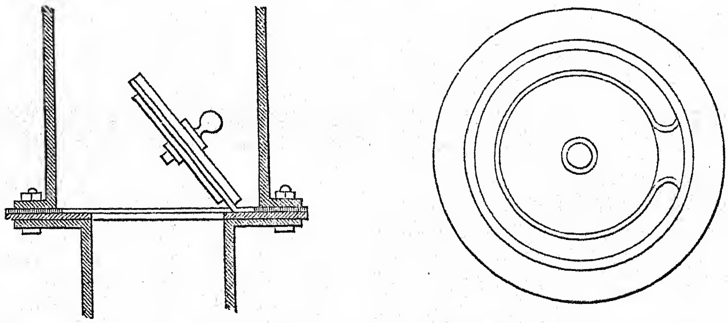


A single-acting pump requires two clacks—one is placed upon the suction-pipe, the other upon the rising-pipe. Sometimes one of these clacks is placed upon the piston itself, which, in this case, is pierced for an orifice suited to the passage of the water. A double-acting pump has four fixed clacks, but none upon the piston. In order to facilitate the examination and repair of these clacks, the pipes are enlarged near their seats.

Clacks, or valves, are of two sorts—spindle valves, and common valves with hinges. The first are sometimes nothing more than truncated cones of small height, which enter and fit closely into the aperture they are intended to shut; they are traversed by a spindle to which they are fastened, and which serves to guide them in their motions. The common valves are usually nothing more than circles of greased leather attached to the aperture they are intended to close by a band of leather forming the hinge. Frequently a sheet of lead is fastened to the top of the leather to keep it flat, and to give it sufficient weight. When greater perfection is required, the leather is placed between two discs of metal; the one above the opening being rather larger than the aperture, the one below smaller.

In large pumps the valves are of brass, sometimes $\frac{1}{2}$ an inch thick, working upon hinges; but it is not advisable to use such valves when the waters to be raised contain any solid matters, for a very little sand would seriously interfere with their action.

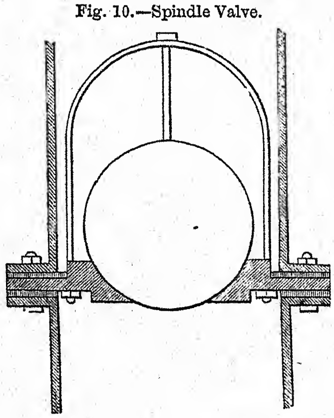
Figs. 8 and 9.—Common Valves.



Whatever be the material adopted, the exterior surface of the valve must be made as nearly as possible of the same dimension as the opening, because any excess of circumference increases the resistance.

The suction and ascension pipes need not be turned. Their diameter is generally less than that of the pump-barrel, and is usually made about two-thirds.

Fig. 10.—Spindle Valve.



If the piston made a perfect vacuum, the water would be raised in the suction-pipe to a height of between 32 and 33 feet above the water level in the well, or to a height sufficient to balance the atmospheric pressure at the point where the pump is placed, whatever may be the diameter of the pipes or their inclination. But in practice, when the piston is at the bottom of its stroke, the pressure of the air occupying the space between the piston and the suction-valve being, without taking into account the weight of the valve, equal to the atmospheric pressure when the piston arrives at the head of its stroke, this pressure becomes

$$H \frac{q}{Q + q}, \text{ in which}$$

H = atmospheric pressure,
q = volume of air between the piston and valves at bottom of stroke,
Q = volume produced by the piston in one up-stroke,
$Q + q$ = volume occupied by the air when the piston is at the top.

In order, then, that after a certain number of strokes the pump may draw, it is necessary that the maximum height of the valve above the water designated by x, and leaving out of account the weight of the valve, should be

$$x = H - H \frac{q}{Q + q} = H\left(1 - \frac{q}{Q + q}\right).$$

The water must not only enter the lower part of the pump, but it must also reach

the highest point of the stroke of the piston. Instead of the theoretical height above given, it is rarely found that in practice it ever exceeds 29 feet, and the maximum average is usually from 26 to 28 feet. The height of the suction-pipe itself is rarely made more than from 17 to 23 feet.

For more detailed information upon the principles affecting the construction and the action of pumps, the reader is referred to D'Aubuisson's Traité d'Hydraulique, or to the Tracts upon Hydraulics, Hydrostatics, and Pneumatics, published by the Society for the Diffusion of Useful Knowledge.

2. *Archimedean Screw.*

This machine appears to have been used in very remote antiquity, nearly in the form adopted at the present day. It is of great service in raising water from positions where the difference of level is not considerable.

If upon the surface of a cylinder a helix of several convolutions or wheels be traced, and if, in a groove cut according to this curve, small planks of the same height be placed side by side in close contact, their combination will form the thread of a screw with a great projection and of a uniform thickness; and if the whole be then enclosed in a solid envelope, the machine will form an Archimedean screw.

In common screws, three equidistant threads are placed, forming the channels; the diameter of the thread, which forms necessarily that of the enclosing case, varies from 13 to 26 inches, the central shaft occupying about ⅓rd of the diameter; and the length of the screw is from 12 to 18 times its diameter. The angle which the thread forms with the axis has been frequently modified in practice. The ancient Romans made it 45°; in the South of France, as in Holland, it is made about 54°; the engineers of Paris make it 60°; and Eytelwein, in some of his experiments, carried it to 78°. At the upper end of the axis is a winch or crank, and at the lower is the pivot upon which the screw turns. Large screws are made even 6 feet 6 inches diameter.

If such a machine be set to work upon a body of water, giving to the axis an inclination less than that of the thread upon the axis,—that is to say, giving the latter an inclination of from 30° to 45°,—and if a rotatory movement be communicated in a direction opposed to that of the threads, the lower orifices of the channels in passing through the water will take up a certain quantity, which will pass from spire to spire and flow out at the top.

Experiments made by M. Lamandé shew that a good screw, of the following dimensions, is capable of producing the results indicated below:—

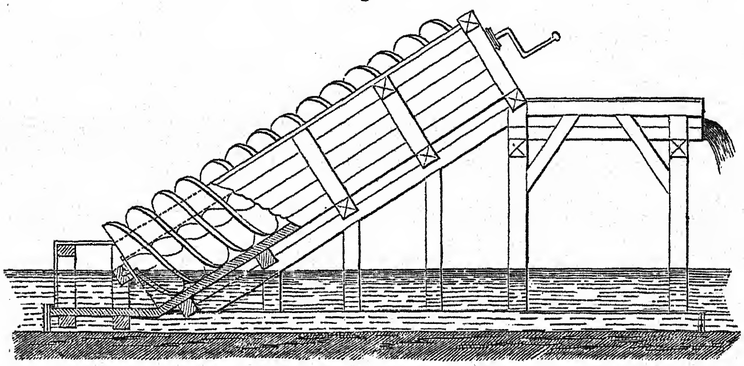
Length of screw	15 feet 2 inches.
Exterior diameter	1 foot 7⅝ inches.
Inclination of the screw to the horizon	35 degrees.
Number of revolutions in a minute	40 ,,
Height to which the water was raised	10 feet 9 inches.
Quantity raised per hour	45 tons.

The useful effect produced by a man working eight hours per day with such a screw would be about 50 tons raised 1 foot high per hour. It is to be observed, that in closed screws it is necessary that the water-line in the well should stand a little above the centre of the base of the shaft, without completely immersing it.

Such closed screws could not be of service for raising water from a well in which the water-line varied. In Holland and Germany this inconvenience is remedied by substituting for the outer cylinder a fixed semicircular channel. By this means also the weight of the outer cylinder and of the water does not bear upon the gudgeons nor upon the shaft, but it is necessary to work the machine with considerable velocity in order to prevent any serious loss of water between the spiral arms and the bottom channel.

In Holland the screws are worked by wind-mills, and they serve to drain the polders and marshes: but it must be evident that the same means could be applied to raise water for irrigation. The Dutch mills have usually sweeps about 40 feet

Fig. 11.



long, measured from the axis of rotation, and they lift the water to a height of about 15 feet. If the point of discharge should happen to be above that height, two or more sets of wind-mills are required, the lower ones pumping the water into intermediate cisterns, from which it is subsequently raised into the discharging channel. These wind-mills cost on the average about 26,000 florins, or £2080 each, and they can raise 86,400 tons of water per day on the average, but they only work effectively 60 days per annum.

The useful effect of an Archimedean screw is stated by Morin to be 0·75 of the power employed.

A French engineer, M. Pattu, in the year 1815 proposed a modification of the screw, consisting in the application of two separate threads on the same axis, one being long and narrow, and the other short and wide. This combination might be rendered serviceable in cases where a fall of water of considerable volume, by setting in motion the shorter screw, might raise the water to a higher level, or where a small stream falling from a great height might furnish sufficient power to raise the water to some intermediate point; or again, in other cases where a short fall existed above the desired point.

A set of screws worked by steam have been erected to make good the waste of water by lockage upon the canal of the Sambre and the Meuse. They are four in number, with a total lift of 21 feet 10 inches, and are open, with a diameter of 5 feet 4 inches. The shaft is of oak, 4 inches diameter, and the blades are 1 inch thick. The generating line of the inner thread is inclined to the axis at an angle of 35°, that of the outer thread at an angle of 72°, the inclination to the horizon being 35°. The play of the screw in the trough is 2 inches, and the machine makes from 40 to 45 turns in a minute, with a depth of 3 feet 4 inches of water in the well. The effect of these screws is to raise 1 ton of water 3 feet 6 inches high per second, for a total outlay of steam engine and all machinery of about £1700.

3. *Machines with Buckets.*

These consist of buckets, swapes, scoops, norias, chain-pumps, and the various descriptions of chapelets.

In raising water by buckets, it is found that a man can only exercise a useful effect

equal to about the fifth part of what he ought to exercise under advantageous circumstances. This mode is therefore rarely resorted to, unless the work to be performed requires to be executed immediately, and is not likely to be of great duration.

When the quantity to be raised is small, and the depth of the water below the point of discharge not more than between 15 and 20 feet, and the operation is only required during two or three hours of the day, it is frequently advantageous to use buckets fastened to a balance-pole. The lever, or pole, is supported upon a post, and carries at the opposite end a counterpoise to the load, so that the greatest effort of the workman is required to lower the empty bucket. In this manner a man accustomed to the labour can raise about 20 tons in an hour. The swape is a machine founded upon this principle, and it has been in use in the East from the earliest periods of civilisation; even at the present day it is retained in Egypt and in India in the same

Fig. 12

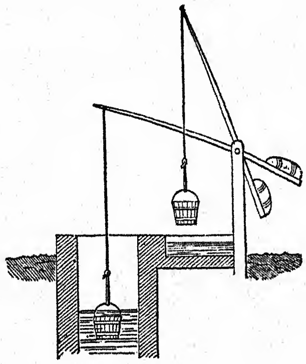
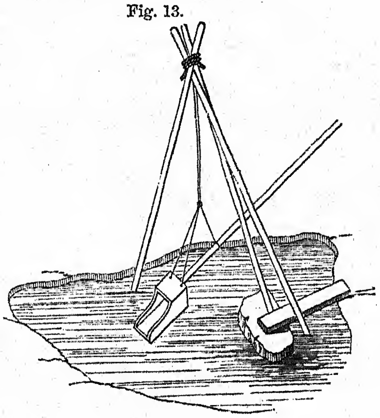


Fig. 13.



form it bears in the hieroglyphics. Fig. 12 represents a similar machine used near Genoa and Savona, and similar rustic implements may be seen in the market-gardens near London.

When the water is very deep in a well, and the use of buckets by hand becomes impossible, they are let down to the water by means of a rope or chain. The most unfavourable conditions for the workman so employed are when the bucket is lowered simply by hand, because the whole effort is upwards, and the weight of the cord is, in fact, so much useless additional weight. The best manner of raising water by ordinary buckets is to fasten the centre of the cord to the drum of a windlass, leaving the two halves to wind upon it in opposite directions. Navier considered that a man working the handle of such a windlass was able to produce a useful effect of 58¼ tons raised 1 foot high in an hour, and to work 8 hours per day.

Hand-scoops are rarely used for the purpose of raising water when the depth of the lower reservoir, below the point of discharge, is more than from 2 to 4 feet.

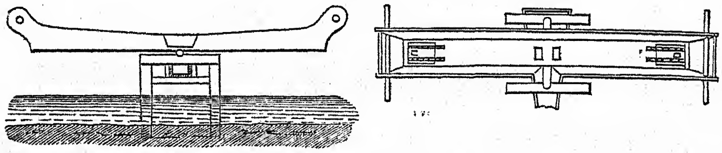
The Dutch scoop, represented by the accompanying sketch, No. 13, is one of the most effectual, and Belidor even states, that with one of these machines the useful effect of a man's labour, working 8 hours per day, is equal to 66 tons raised 1 foot high per hour. This result seems, however, to be too favourable.

The machine represented by fig. 14 is slightly modified from one described by Belidor, in order to render it more susceptible of removal. It may easily be understood that it is worked by two men, and that when they lower the trough, which

moves in an arc of a circle, the valve opens, and the part near it becomes filled with water,—as also that when the movement is changed, the water should flow away from the centre.

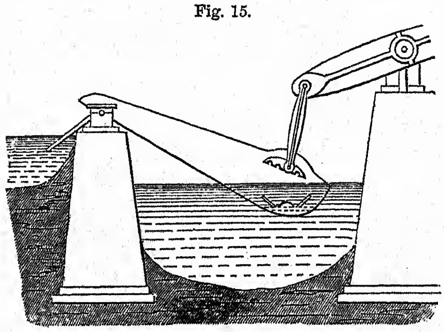
Such hand-troughs can easily raise water from a depth of from 3 to 4 feet, but their principal defect consists in this, that a considerable portion of the power

Fig. 14.



employed is absorbed in raising the trough (which must be of a considerable weight), at the same time with the water. This objection is, to a certain extent, obviated by the troughs being made double, and so disposed as that one side should balance the other,—in fact, by disposing the weight of the machine so that the weight of the water alone should be raised. Four men are usually required to work such a machine, and it is evident that it would be easy, by means of cords, pulleys, beam-engines, or other contrivances, not only to enable workmen to use them more advantageously, but also to admit of the application of other motive power than mere manual labour. Thus Mr. William Fairbairn has designed a machine represented by the sketch No. 15, in which the trough is worked directly by steam, upon the principle of the Cornish engine. The scoop is made of wrought iron, and is 25 feet deep by 30 feet wide, with two partitions across it. The arrangement by which the dip may be altered, without any corresponding alteration in the length of the stroke of the piston, is to be admired; but owing to the scoop not being made double and with an alternate motion, a portion of the power must be lost. It is stated that these machines are adapted to raise 17 tons of water at each stroke, and with an engine of 60 horse-power that they will do a duty equal to 3 lbs. of coal per horse-power per hour. If this be really their effective duty, there are very few water raising machines which can be compared with them, especially in those cases in which the lift should not exceed from about 12 to 15 feet vertical.

Fig. 15.



When water is raised by buckets upon a windlass, it is necessary, that in addition to the men placed at the handles, there should be another at the bottom of the well to place the buckets, so that they should fill rapidly. Sometimes, also, it is necessary to have another man at the top to empty the buckets when they arrive at the surface of the ground. The expense of this method of raising water is, therefore, much increased.

In order to obviate this source of expense, and at the same time to avoid the loss of time consequent upon the intervals of repose whilst the buckets are being filled and emptied, a series of such instruments is placed upon an endless chain, passing

over a drum below the level of the reservoir from which the water is to be raised. The lower extremity of the chain, and the buckets it carries, dip into the water; their opening is turned upwards upon the ascending portion of the chain, and downwards upon the descending portion. The machine, of which the above description indicates the principal parts, is called the Noria, and is set in motion by a crank, or by toothed wheels communicating with a mill. In passing through the water, the buckets fill themselves with water, and they carry it with them to the top of the ascending chain; when they arrive at the top they incline laterally, according to the convexity of the upper drum, and they pour their water into a basin or trough placed to receive it.

In this manner the buckets fill and empty themselves, and the continuity of movement is attained. But at the same time that the noria possesses these advantages, it has some defects: thus the water forcibly is raised to a higher point than that of discharge, and the great weight of the machine, as well as the number of joints, augment considerably its resistance, its friction, and the expense of repairs. In spite of these defects the noria is a very useful instrument, and it has been in use in the East for many centuries. The Arabs carried it with them into all the countries of Southern and Western Europe they conquered, and it is unquestionably to them that the inhabitants of Spain and of the South of France owe its application to the purposes of irrigation in their gardens.

Originally the chains were formed simply of wisps of hay or straw, the buckets were only common earthenware vessels, and the drums, both above and below, were nothing more than ends of timber rudely crossed. Such is even at the present day a description of the majority of norias used in Spain, Italy, or Egypt, and although rustic, and rude in the extreme, they effect tolerably the proposed object. In the best modern norias, however, the buckets are made either of sheet-iron or of copper; the chains are of iron; the toothed wheels are of cast iron, as are also the drums.

D'Aubuisson cites, as a very perfect machine, a noria made by M. Abadie, of Toulouse. It consists of a drum of hexagonal form, 18 inches in diameter and about 17 inches long. The axle of the drum is of iron, and $5\frac{1}{2}$ inches square; the chain is about 45 feet long, and contains 28 links, each of which carries a bucket of sheet-copper able to hold $3\frac{3}{10}$ gallons. The surface of the basin which receives the water is about 3 inches below the axle of the drum, and 16 feet 10 inches above the level of the water in the well. A common horse, used for gardening purposes, works this machine, and produces a useful effect of about 400 tons raised 1 foot high per hour, or about 0·82 of the real power employed to set the noria in motion. Navier made some experiments, which appeared to shew that the useful effect was about 0·88 of the power, but in practice it is not advisable to reckon upon more than 0·70 to 0·80.

As already seen, it is necessary in a noria that the water should be raised to a point above that of discharge, in order that the buckets may empty themselves. It follows from this, that in order to produce an effective result $Q\,h$, it is necessary, leaving out of account all friction, to produce a real effort $Q\,(h + h')$ in which

$Q =$ the weight of the water,

$h =$ the height of the discharge,

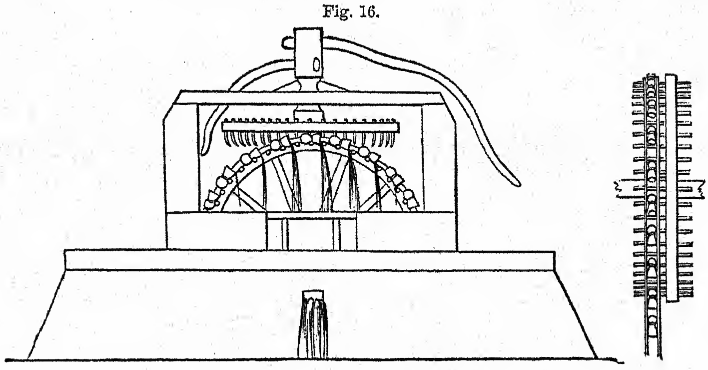
$h' =$ the extra height required to enable the buckets to discharge the water at a proper height: this is usually about 2 feet 6 inches, or the radius of the circle described round the hexagon formed by the drum, with a play of from 4 to 8 inches.

As the value of h' remains constant, whatever be that of h, the proportion of the useful effect to the power employed will be increased as h increases, and this theore-

tical deduction has been confirmed by direct experiment. The power thus lost is, in addition to that cited above, represented by the coefficient 0·82, so that the real expression of the useful result would be $\frac{400}{h + h'}$.

There are many other machines for raising water which produce more favourable results than the noria, with reference to the proportion between the power employed and the useful effect produced. But the noria has the twofold advantage, that its simplicity of construction is such that a common blacksmith can repair it, and that it can raise waters, however muddy or charged with sediment. To secure the most favourable results it is advisable that the movement should be slow. The depth to which it can work favourably appears to vary from 8 to 10 feet at a minimum to about 45 or 50 feet at a maximum.

Fig. 16.



The sketch, No. 16, illustrates the noria used in Spain; the pots are of earthenware, the chains replaced by haybands, and the machine is set in motion by a horse or an ox. According to Jaubert de Passa, from whose work 'Voyage en Espagne' the sketch is extracted, by the aid of one such noria it is possible, under the burning climate and the sandy soil of that country, to supply the wants of a family from three or four acres of land.

Chain-pumps may be taken as representing what foreign engineers describe under the name of Chapelets, and they are of two kinds, the vertical or the inclined chapelet. They were formerly much used in drainage works, and, it appears, are still retained in China for raising water for irrigation; but their use has been almost entirely superseded by the Archimedean screw or by other machines in Europe or America.

The vertical chapelet consists of a tube, either cylindrical or square, about 13 or 20 feet long and 5 or 6 inches diameter: the lower end of this tube is placed in the water. Above the tube is placed a wheel or roller, fixed upon an axle, at the ends of which are winch-handles. An endless chain works upon the roller and in the vertical tube, bearing from distance to distance a series of valves of wood or of metal, lined with leather, fitting tolerably closely against the sides. A second roller is placed at the bottom to guide the chain, and to keep it constantly in a state of tension.

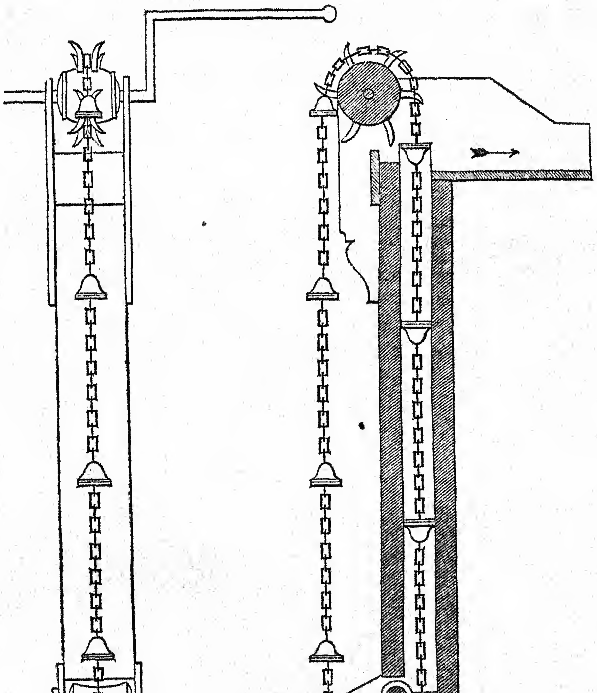
When the chapelet is in motion, the upper roller moves the links successively, and thus raises the chain. The valve which arrives at the lower orifice of the tube then takes the water below the preceding valve, intercepts its communication with the lower reservoir, and carries it to the discharging channel.

In cases where the height from which the water has to be raised does not exceed 13 or 14 feet, the vertical chapelet appears to be advantageous; its machinery is less complicated than that of the noria, and it offers less resistance. A considerable quantity of the water, it is true, escapes between the leathers and the sides of the tube, especially when the speed is small. This loss, however, may be diminished by keeping the machine constantly in repair, and particularly by applying to the lower end of the tube a carefully-bored metal pipe of a rather smaller diameter, and of a length a little more than the distance of one valve from another.

It is usual to employ from four to eight men at the winch-handles, which have a radius of about 1 foot 4 inches, and make from 20 to 30 revolutions a minute, to work these vertical chapelets. Working 8 hours per day, and relieved every 2 hours, these men raise from 370 to 400 tons 1 foot high in a day. In general, it may be assumed that the useful effect is equal to 0·65 of the labour employed, and that the quantity of water raised is about five-sixths of that entering the tube.

The chapelets may be worked by manual labour, or by horse, steam, or even by water-power.

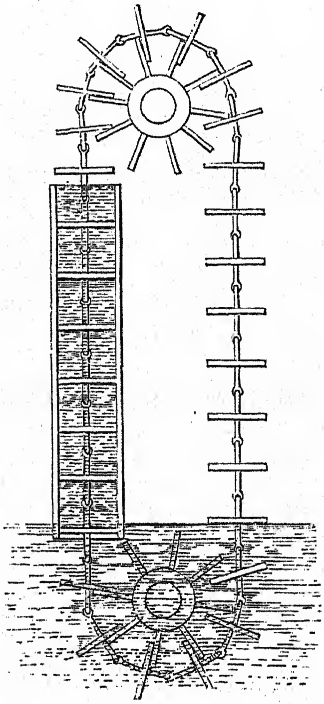
Fig. 17.



The inclined chapelet consists of a series of valves attached to an endless chain, usually of a rectangular form, and working in an inclined trough. The descending branch of the chain bears upon the upper side of the trough, if it be covered, or upon

a species of floor, should that not be the case. The trough dips into the well, and is carried to the point where it is desired to pour the water.

Fig. 18.



The play left between the exterior of the valves and the sides of the trough is not more than $\frac{1}{4}$th of an inch. For the same sectional area of valve the development of the part of its contour in contact with the trough is the least, as is likewise the quantity of water it allows to escape, when the height is equal to half the width; nevertheless in practice the height is sometimes made equal to four-fifths of the width. The distance between the valves varies from 1 to $1\frac{1}{2}$ times the height, and the speed from 3 feet 6 inches to 5 feet per second.

The inclined chapelet requires a greater motive power than the vertical chapelet proportionally to the effect produced,—on account, firstly, of the friction of the valves, and, secondly, on account of the loss of water between them and the sides of the trough. In Europe, therefore, this mode of raising water has long since been abandoned; but it is retained in China, where the low price of labour may still justify its use. Peyronnet was one of the last to employ the inclined chapelets, and it appears from the experiments and observations he made that the real useful effect they produced did not exceed more than 0·40 of the power employed. (See figs. 17 to 20.)

Fig. 19.

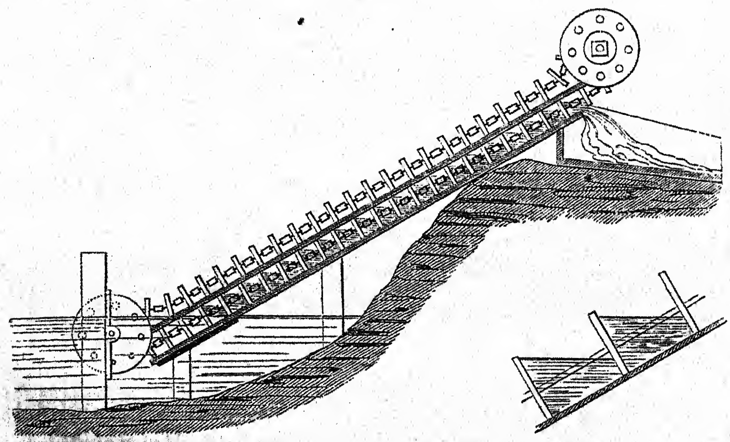


Fig. 20.

4. Water-wheels, with buckets, &c.

It is possible to apply to the circumference of a water-wheel, the lower part of which works in a stream, a series of buckets, which are open, and so disposed that at the lower part of the revolution they should take up a certain quantity of water to be afterwards discharged into a basin constructed to receive it. There is no simpler or more economical method of raising water; the same current furnishes the power and the material required. For these reasons, when local circumstances admit of its application, this kind of machine is frequently used for irrigation or domestic purposes.

When the depth from which the water is to be raised is considerable, a separate wheel is constructed for the buckets and for the floats. The first consists of two circular plates, between which the buckets are placed, in the best wheels of this description, upon an axle which traverses the upper part, and around which they are free to move. In this manner they remain vertical, and retain the water they have taken up until they arrive at the top of the wheel; there a very simple piece of mechanism causes them to incline, the water falls out, and they reassume their position. The float-wheel communicates movement to the bucket-wheel either by an axle common to the two, or by any other contrivance. In rough country works, however, the floats are occasionally arranged at fixed distances to act as buckets, which, by the movement of the wheel, successively takes up the water, and pours it into the reservoir. Unless, however, the openings of the buckets be well regulated, they always lose a portion of the water they take up at the moment they leave the stream; moreover, the water is not discharged until it reaches a point higher than the one where it is required to be used. For these reasons, the loose buckets above mentioned are preferred.

Peyronnet used a similar machine to that described with considerable success for draining the foundations of the Neuilly Bridge. The float-wheel was fixed at a point in the stream where the velocity was about 2 feet 8 inches per second, and the bucket-wheel was removed to the different piers, sometimes to a distance of 116 feet. The first wheel was 19 feet 2 inches in diameter, the width of the floats was 21 feet 4 inches, and their height was about 3 feet $2\frac{3}{4}$ inches. The second was 17 feet 7 inches in diameter, and carried 16 buckets, or cases, each of which cubed about 5 cubic feet, but did not lift to the top much more than $3\frac{1}{2}$ cubic feet. This machine raised 185 tons per hour from a depth of from 10 feet 6 inches to 12 feet 10 inches,—a useful effect equivalent to that of twelve vertical chapelets, such as Peyronnet employed for the works of the same bridge.

The machine known to the ancients by the name of the tympanum is but a modification of the bucket-wheel. It consists of two plates and a cylindrical envelope, to which they serve as a base. It is divided interiorily into eight, or a greater number of, compartments by a series of partitions disposed in the direction of the radii. The cylindrical envelope is pierced by a series of holes, one corresponding to every opening or division in the interior of the wheel, and the exterior drum is pierced by a large axle, upon the face of which are as many openings as there are compartments.

When this machine is properly placed upon the water to be raised, and it is set in movement, each opening, as it passes below the level of the water in the reservoir, takes up a certain quantity of water, which passes into the receiving tank by the openings in the face of the wheel.

At the beginning of the last century Lafaye modified this wheel by making the compartments according to the development of a cycloid generated by the revolution

of a circle equal to the diameter of the axle, and by suppressing the external case. By this disposition, a vertical line passing through the centre of gravity of the body of water contained in each division is tangent to the axis; and whatever may be the position of the tympanum, the radius of its axis is the expression of the resistance; so that the effort is as regular as possible.

Peyronnet made some elaborate observations upon the effect produced by these wheels. The tympanum he used had a diameter of 19 feet 2 inches, and carried 24 partitions, entering the water to a depth of nearly 10 inches. It made 2½ turns per minute, and raised 123 tons of water to a height of 8 feet 6½ inches per hour,—the motion being communicated by 12 men working a wheel with a lantern; so that the useful effect of a man's labour per hour was equal to 87·8 tons raised 1 foot high. The proportion this bears to the useful result of a vertical chapelet is about 26 to 17. But the tympanum has the serious objection of not being able to lift the water above the axis, which entails the necessity of making it of considerable dimensions, and therefore very heavy and cumbersome. It may be driven by water, steam, horse, or hand labour, as may be necessary.

In England this description of wheel is known as the Persian wheel, but it is very rarely employed. Its antiquity is very great, for Vitruvius mentions it, and even very correctly cites its advantages and disadvantages: "Non alte tollit aquam, sed exhaurit expeditissime multitudinem magnam."

The *flash-wheel* works upon the same principle as the chapelets, but its operation and effects are confined to a circular channel, in which the flat blades move. In Holland these wheels are used to raise the water occasionally from the marshes, and they are there set in motion by wind-mills. Near Paris, in the basin of St. Ouen, a machine of this nature was constructed for the purpose of lifting water from the Seine. The principal dimensions were as follows:—

Exterior diameter of the wheel	35 ft.
Interior do.	29 ,, 7 in.
Length of floats . . , ... (nearly)	4 ,,
Height of do. measuring upon the inclined line of the floats .	3 ,,
Do. do. measured upon the radius	2 ,, 8½ in.
Number of floats	36

The observations made upon the working of this engine shew that it raises 2200 tons of water 13 feet 2 inches high in an hour: the power of the machine setting it in motion being 45 horses, it follows that the real effect produced is 0·82 of the power employed; but as the power of the engine was not accurately ascertained before the trials, the results are only to be considered as approximations.

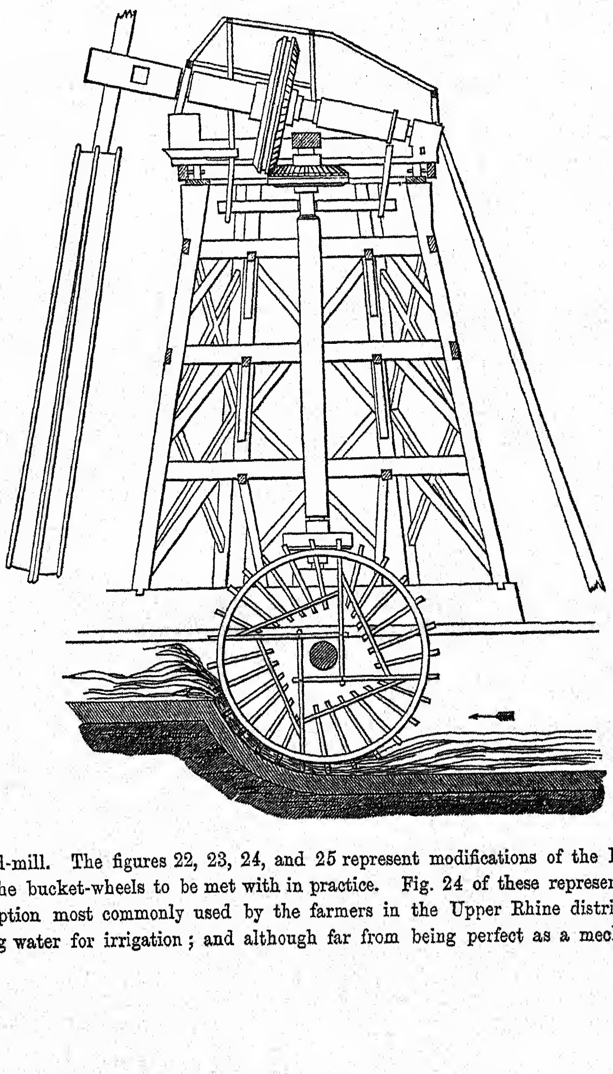
Smeaton and Navier examined the action of these wheels. Smeaton states that their results are even more favourable than those cited above, but his experiments must be considered rather as ascertaining maximum than mean results. Navier found that the useful effect bears a greater ratio to the power employed when the speed of revolution is the least, and that theoretically the effect and the power would be equal if the speed were infinitely small. But at the same time the loss of water between the circumference of the blades and the race increases when the speed of revolution diminishes: all other things being equal, this loss may be reduced to the lowest terms by making the blades rectangular, and of a width equal to double their height.

This description of wheel is liable to the same objection as the Persian wheel, viz. that the water cannot be raised above the level of the centre of the axle. Nevertheless, in the fen districts of Lincolnshire Mr. Glynn has lately erected some powerfu

machinery of this nature. One of these erected on the Ten-mile Bank, near Littleport, in the Isle of Ely, is driven by an 80 horse-power engine with a wheel 40 feet diameter. The Deeping Fen, near Spalding, with an area of 25,000 acres, is drained by two engines of 80 and 60 horse-power. The 80 horse-power engine works a wheel 28 feet diameter, with float-boards $5\frac{1}{2}$ feet by 5 feet, and moving with a velocity of 6 feet per second on the average. When the engine has its full dip, and consequently the sectional area of the blades lifting the water is $27\frac{1}{2}$ feet, the quantity discharged per second is 165 cubic feet, or about $4\frac{1}{2}$ tons raised 5 feet in height. The useful effect of this engine would thus appear to be 0·88 of the nominal power; but the remark made above with reference to the engine of St. Ouen applies equally in this case, viz. that little dependence can be placed on the nominal expression of the power of a steam engine.

The figure 21 represents the flash-wheel arranged so as to receive its motion from

Fig. 21.



a wind-mill. The figures 22, 23, 24, and 25 represent modifications of the Persian and the bucket-wheels to be met with in practice. Fig. 24 of these represents the description most commonly used by the farmers in the Upper Rhine districts for raising water for irrigation; and although far from being perfect as a mechanical

contrivance, it is found to render very great service. Its simplicity of construction is

Fig. 22.

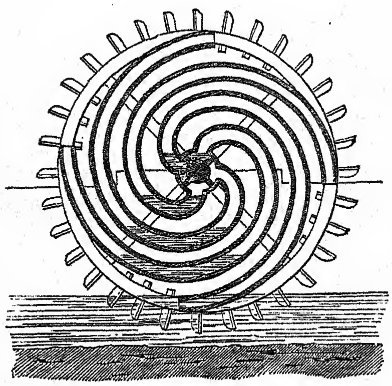


Fig. 23.

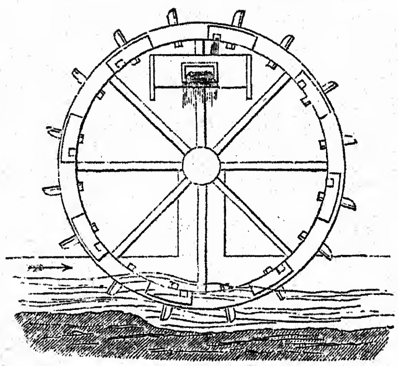


Fig. 24.

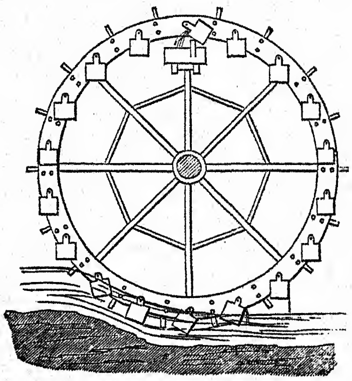
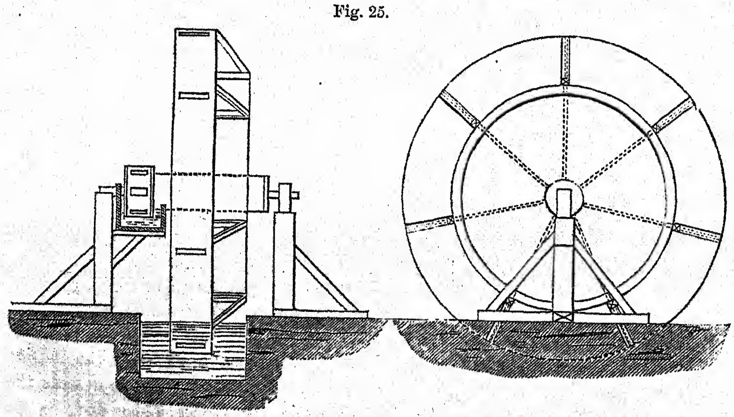


Fig. 25.



such that any village carpenter can make it, and as easily keep it in repair. The

emigrants from this district have carried their bucket-wheel into the United States, where it is applied with the same success as in the mother country.

5. *Miscellaneous Machines.*

The class of water-raising engines thus grouped together have little, if any, connection with one another.

The most important of these machines, when an intermediate point of discharge can be found for the water creating the power, is the water-column engine of foreign engineers, formerly known in England as the 'Hungarian Water-pressure Machine. It consists of a cylinder or large pump-barrel, in which a piston moves, driven by the weight of a high column of water confined in an upright pipe; a rod or balance-beam is fastened to the head of the piston, which communicates movement to common pumps or other implements; sometimes, but rarely, a system of machinery is adopted which converts the alternate up-and-down motion into a circular one: this conversion of movement, we may remark, is never effected in the best and most modern machines of this description.

One of the most perfect water-pressure engines has been erected at Huelgoat, by order of M. Junker. It is single-actioned, and the principle upon which it works is similar to that of the Cornish engine; but the transmission of the pressure of the water has led to some important modifications in the details of its construction. The principal condition required in these engines is, that water should be obtained in a vertical column of sufficient height, and that it should be discharged after the pressure it is exposed to at the bottom of the column has produced its effect. As in the Cornish engine, the manner of application consists in directing this force so as to raise a piston lifting the load, and then in cutting off the communication when the cylinder is full, giving free egress to the water which has thus created the power, and allowing the piston-rods to fall by their own weight.

In the lifting machines of Huelgoat, the cylinder producing the motion is placed with the cover downwards, and it is open at the top; it bears at the bottom a shoulder, which is successively put in communication by means of an upright pipe with two pipes, the one leading to the base of the water column, and the other to the discharge heading; these therefore serve as the conducting and discharge pipes for the water producing motion. To set the machine at work, it will suffice to place the shoulder at the bottom in communication with the feed-pipe; then when the piston shall have traversed the whole of its course, to close this orifice, and to put the cylinder in communication with the discharge pipe, so that the water may be driven out by the weight of the piston and of the pump-rods, which produces the down-stroke.

At Huelgoat there are two machines of the nature described, designed to raise the waters filtering into the mine, which it is supposed may amount to 200 tons per hour. They are placed about 360 feet below the surface of the ground, in the midst of the well designed to collect the waters, the bottom of which is about 1080 feet from the surface.

The cylinders are 3 feet 4½ inches diameter and 9 feet high. The piston is of brass and is simply covered with leather; the stroke is a little more than 7 feet 6 inches long, and the machine makes on the average 5½ strokes per minute. A wrought-iron rod is attached to its centre, which passes through the bottom of the cylinder and descends vertically to the bottom of the well: it is designed eventually to raise the water at one lift a total height of nearly 755 feet, to an overflow channel. The descending column is of a total height of 246 feet 8 inches, but as 46 feet 8 inches of this is lost by placing the machines below the level of the overflow, the effective head upon the cylinder is only 200 feet. The reason for placing the machine in this position was, that it was deemed advisable by this means to counterbalance the weight

of the pump-rods. The equilibrium is thus produced to a certain extent by a column of water 46 feet 8 inches high, with a base of 3 feet $4\frac{1}{2}$ inches diameter.

The diameters of the feeding and discharge pipes are nearly 15 inches each, that of the pump-barrels is 18 inches, and that of the rising main $10\frac{7}{8}$ inches.

In this description of machine the piston receives the whole power of the water producing motion, excepting the small portion required to work the regulators, and nearly all the fall H is used, so that the dynamical effect ought to be very nearly expressed by P H; P = the weight of water. But the friction of the piston in the cylinders, the resistance the water is exposed to in the pipes, and the various bends, absorb a notable portion of the power; so that even in the best machines the real effect is only equal to about $\frac{2}{3}$rds of that found by theory. In the best water-column machines of Freibourg, the maximum of the real effect rises to 0·70 or even to 0·75. At Huelgoat the engines do not work to their full power, so that actually they only produce 0·45 P H, although it is supposed that when the workings of the mines shall have been carried to the depth originally intended, they will yield 0·75 P H. M. Junker, however, has deemed it safer not to calculate upon a real effect of more than 0·65 P H.

Some water-pressure engines produce their effect merely by the compression of the air in an intermediate chamber. But such engines, although the philosophical principle upon which they are founded be very elegant, are not of sufficient practical utility to require a long description. The reader is therefore referred to Dr. Gregory's 'Treatise on Mechanics' for the details connected with their action and construction.

The Hydraulic Ram of Montgolfier.

The hydraulic ram was invented by M. Montgolfier, of Paris, about the year 1797, and is very remarkable both on account of its simplicity and of the peculiar principle of its action. This would appear to depend upon the momentum of any body once set in motion continuing to operate after the movement itself shall have ceased in that body.

This machine consists, firstly, of either a feeding reservoir, or a conducting pipe, M; of a pipe forming the *body of the ram*, A B, which conveys the water to the working part: this last is called *the head*, and consists in a short pipe C D, open at its upper end by means of an orifice *e*, against the edge of which works a valve *a*, intended to close it. The head also contains the rising valve *b*, which opens upwards into a reservoir called the *air vessel*, and at the bottom of the air vessel is placed the ascending pipe E.

The form as well as the respective positions of the parts of these machines may differ, as is shewn by the accompanying sketches, figs. 26 and 27. In the latter the

Fig. 26.

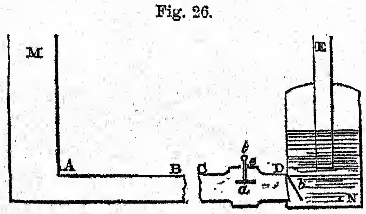
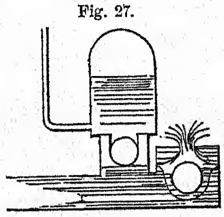


Fig. 27.



valves are replaced by hollow globes, whose specific gravity is twice that of water. They are retained in their position by iron bars, which nevertheless leave them at perfect liberty to move in the required directions; the seats of the openings are lined with tarred yarn, in order to break the jar occasioned by their falling into their seats.

Now, if we suppose that the valve *a* be drawn down, the water will flow from M along A B, and escape through the orifice *e*. Whilst the water is thus flowing, the weight of the valve *a* must be adjusted by means of the spindle *t* placed to receive a load, so as just to sink or force its way down against the head of water in A B. When the water, however, is in motion it acquires considerable momentum, and exercises a power greater than that of the mere column to which the valve has been adjusted. The valve *a* is then raised, and the orifice *e* closed, and the flow of the water being thus checked, it becomes stationary, the momentum is lost, the valve and weight then again become superior, and they fall, opening the valve, so as to let the water escape again. In this manner, as the pressure of the water and the weight of the valve become alternately superior, the valve is kept in a constant state of vibration without any external aid whatever.

It must be evident that in the mean time the momentum generated between each pulsation cannot be at once destroyed; a second valve *b* is then provided, through which the water is forced into the air vessel, until the elasticity of the air overcomes the gradually decreasing momentum, when the valve *b* closes, and that at *e* opens, to allow of a second pulsation. The same series of movements will be repeated so long as the upper reservoir shall continue to supply water.

M. D'Aubuisson cites as one of the most powerful machines of this class the hydraulic ram constructed at Mello, near Clermont-sur-Oise, by Montgolfier the younger. The body of the ram is $4\frac{1}{2}$ inches in diameter, 106 feet 7 inches long, and weighing about 29 cwt.; the head weighs 4 cwt.; the capacity of the air vessel is only 1·32 gallon. The valve (*a*) consists of a flat plate, in which are seven holes, closed by the same number of hollow balls $1\frac{1}{2}$ inch diameter. It beats 60 strokes per minute. (In the subjoined Table more details are given of this engine.)

Hitherto the reactions which take place in the working of the ram have baffled all attempts to form any satisfactory theory upon their causes, and the practical results they have presented have been too discordant to allow of the establishment of any general formula, possessing tolerable accuracy, by which the proportions of the different parts of the machinery can be predicated, or by which the relation between the power employed and the effect to be produced can be expressed without a separate trial in every case. The passive resistances, especially those of the valves, present in fact so many difficulties as to render their appreciation nearly impossible.

In the following Table, extracted from D'Aubuisson, and from Hachette's 'Traité des Machines,' it is to be observed that the estimation of the effect of the hydraulic ram, unlike water-wheels, does not require that the velocity of the movement should be taken into account. The effect will be the weight of water raised to a certain height in a certain given time; calling the weight p'' and the height H', it will be $p'' H'$. The corresponding force P being the weight of the water furnished in the same period, and H the height of its fall, its expression will be PH, and consequently the relation between the two will be $\frac{p'' H'}{PH}$; or it will be $\frac{q H'}{Q H'}$ if q represent the volume of water raised, and Q that employed to raise it, since $Q : q :: P : p''$.

Number of experiment.	Height of fall. H.	Height of elevation. H'.	Water employed Q.	Water raised. q.	$\frac{q H'}{Q H}$
1	2·m60	16·m06	0·m068	0·m00624	0·570
2	11· 37	59· 44	0· 140	0· 0175	0·653
3	10· 60	34· 10	0· 084	0· 017	0·651
4	0· 98	4· 55	1· 987	0· 269	0·629
5	7· 00	60· 00	0· 013	0· 00097	0·671

The average of these experiments gives 0·65 as the ratio between q H′ and Q H.

Hitherto the hydraulic ram has only been used when the quantity to be raised has been small, and it is very doubtful whether the machine would ever be able to produce any powerful action. The violent shocks of the valves, and the jar of the body of the ram, shake the supports in a very dangerous manner. It is for the purpose of obviating this that the weight of the body of the ram is made as great as possible, but in this manner the evil is only partially remedied. In the large hydraulic rams, the heavy bed-work in which they are fixed becomes loosened in course of time, notwithstanding any care or pains employed in its execution. It is therefore to be feared that the use of this very important hydraulic engine must be confined simply to supplying the wants of one establishment.

Belidor's Pressure Engine, and *Bramah's Hydrostatic Bellows,* are merely modifications of the Hungarian Pressure Engine. As the latter, in the conditions of the Huelgoat machines, combines all their useful details, it will not be worth while to dwell more at length upon them, more especially as they are rarely used for the purpose of raising water. It may, however, be appropriate to state that the theoretical pressure able to be exercised by the great piston of an hydraulic press is, $Q=\frac{PLD^2}{l\,d^2}$.

Q = the pressure produced.

P = the motive power: a man acting upon a lever without employing the weight of his body produces ordinarily $P = \frac{1}{2}$ cwt.; or even $P = 1$ cwt., if the effort be not of great duration.

L = the leverage of P, or the distance of the point of application of this force from the axis of rotation of its lever.

D = diameter of the large piston.

d = diameter of the small piston.

l = leverage of the resistance offered by the piston to the movement of the lever of P: this resistance is equal to the pressure of the water upon the small piston, or to $P\,\frac{l}{L}$.

But the passive resistances of the machine, and especially the friction of the piston against the sides, diminish the real value of Q, so that it varies from 0·80 Q for small efforts to 0·85 Q for greater ones. The ratio of the speed of the large piston to that of the smaller one is equal to the inverse ratio of the sections, or of the squares of the diameters of these pistons.

The Rope Pump of Vera, although rarely employed, in some positions might be made to render very valuable service on account of the simplicity of its construction, notwithstanding the useful effect produced is but small.

It consists of an upper and lower pulley formed in the usual manner, but with several grooves in each; endless ropes of loosely spun horse-hair or wool are made to revolve with great rapidity upon these, by means of a multiplying wheel connected with the upper pulley. The lower pulley, together with a great part of the ropes, moves in the water, which is merely raised by adhesion to the ropes and the rapidity of their motion.

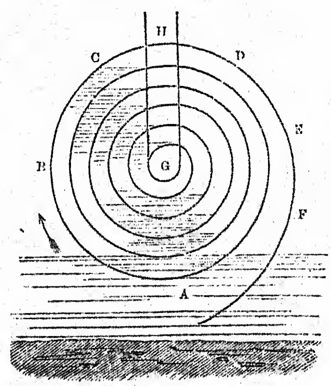
Water has been raised in this manner about 180 feet by a rope $1\frac{3}{4}$ inch girth, but the useful effect was only $\frac{2}{3}$ths of that which could have been obtained by a windlass and buckets. Perhaps larger cords and a less lift might increase the useful results, but this machine can only be recommended in cases where hand-labour is easily obtained, and it is difficult to get the repairs of more perfect pumps economically performed, as, for instance, in some of our Eastern Colonies.

The machine invented by M. Viallon consists of the application of the 'canne hydraulique' of the French engineers,—a term for which we have no equivalent, so little is the machine known. An upright pipe is placed in the liquid to be raised, and upon the botttom a valve opening upwards is introduced. If the lower end of the tube be sunk from 12 to 15 inches below the surface, the water will rise through the valve, and stand at the same height within as without. If the tube be now raised quickly, but not above the water, the valve will close, and the water within will be carried up with it: when the machine is thus at the highest point, let the motion be suddenly reversed, and it will be found that the liquid column within will continue to ascend until the momentum imparted to it at first shall have been expended. A vacuum will thus be formed in the lower part of the instrument, into which a fresh portion of water will enter. After this operation has been repeated several times, and if the movement be well regulated, the valve becomes useless, for the water in the pipe will acquire a constant ascensional movement.

The effect evidently depends upon the rapidity with which the instrument is worked,—*i.e.* a sufficient velocity must be given to the water by the upward stroke to prevent its descending till the tube again reaches the lowest point. The tube must be straight, and the bore perfectly smooth and uniform, that the liquid may flow through with the least possible obstruction. As its length must be equal to the elevation to which the water is to be raised, it is necessarily of limited application, and especially so since the whole (both water and apparatus) has to be lifted at every stroke,—not merely the liquid that is discharged, but the whole contents of the machine.

By making one portion of the tube to slide upon another that is fixed, it would be possible to obviate this inconvenience to a certain extent; but practically it is found that the loss of power is so great as to render the use of this machine too expensive for ordinary purposes.

Wirtz's Pump is rather an ingenious combination of the Persian wheel and the pressure engine. It consists of a spiral pipe coiled round in one plane, the interior end of which at G is united to an ascending pipe H, and the open end is enlarged so as to form a scoop, A. In operation, the air and water respectively enter the scoop; the body of water in each coil will have both its ends horizontal, and the included air will be of about its natural tensity; but as the diameters of the coils diminish towards the centre, the column of water which occupied a semicircle in the outer coil, will occupy more and more of the inner ones as they approach the centre G, till there will be a certain coil, of which it will occupy a complete turn. The water will consequently run back over the top of the succeeding coil, and push the water within it so as to raise the other end. As soon as the water rises in G H, the escape of air is prevented, and the water entering the scoop on one side, together with that in the tube G H on the other, will press upon the air between them, and the water will be forced up G H to a height corresponding with the elastic force of the air; but the height to which it can be raised can never exceed the sum of the altitudes of the liquid columns in the coils.



List of Authors consulted.

A Treatise of Mechanics, by Dr. O. Gregory—Encyclopædia Britannica, art. 'Hydraulics and Rivers'—Treatises upon Hydrostatics and Hydraulics, published by the Society for the Diffusion of Useful Knowledge—Encyclopédie Roret, art. 'Irrigation et Assainissement des Terres'—D'Aubuisson des Voisins, Traité d'Hydraulique—Claudel, Formules à l'Usage des Ingénieurs—Morin, Aide-Mémoire de l'Ingénieur—Belidor, Architecture Hydraulique—Navier, Résumé des Leçons donnés à l'Ecole des Ponts et Chaussés—Hachette, Traité des Machines—Peyronnet, Œuvres de (in 4to)—The Works of Bidone, Michelotti, Dubuat, Coulomb, Mariotte, Poncelet, Eytelwein, Wiebekin—Philosophical Transactions of Royal Society—Tatham's Treatise on National Irrigation—Stephens on Irrigation—Baird Smith's Italian Irrigation; Ditto, Irrigation of the Madras provinces; Selections from the public correspondence of the late E. I. Company's departments—Nadault de Buffon, Traité de l'Irrigation; Ditto, Cours d'Hydraulique Agricole—Sproule's Practical Agriculture—Girardin, Traité de l'Agriculture—Annales des Mines—Annales des Ponts et Chaussées—Burat, La Géologie appliquée, &c.—Ewbank's Hydraulics and Mechanics—Sganzin, Cours de Construction.

WATER SUPPLY.* Water is so essential an object in all domestic or industrial operations that the means of securing a copious and economical supply become subjects of the highest interest to the statesman.

Quality of Waters.

All waters are not, however, equally fitted for what we may call domestic purposes. Of late, much has been *asserted* upon the subject, which subsequent examinations would lead us to doubt, especially with reference to the qualities of the particular class of waters containing in solution the bicarbonate of lime. No examination of the physiological bearings of the question has hitherto been made in sufficient detail to allow the exclusion of that, or of any other class of spring water, free from mineral salts in notable quantities. This is to be regretted, for the waters taken into the system are known to produce effects which are not only injurious to the present, but may be transmitted to future generations. M. Chossat, of Geneva, instituted a series of experiments upon birds to ascertain the effect of depriving their water and food of the bicarbonate of lime, feeding them otherwise in the ordinary way. The result was, that their bones were so materially altered that they became unable to support the weight of the body; the calcareous salts of the bony skeleton, were, in fact, reabsorbed into the system. The inference drawn by M. Chossat from these experiments was, that unless the calcareous salts were supplied by the liquid or solid food consumed by human beings, there would ensue a gradual wasting away of the system, which would reappear in the second generation in the form of rickets. The constitutional tendency of the inhabitants of peculiar districts to particular complaints, such as the goître and urinary secretions, which are universally attributed to the chemical nature of the waters, shews that the importance of this branch of physiological inquiry cannot be too much insisted upon.

Without entering in detail into an examination of the action of waters upon the human frame, it may suffice in the present uncertainty attached to the subject to state, in the words of Thénard, that they may be pronounced to be fit for domestic use when they are fresh, limpid, and free from smell,—when they boil vegetables without affecting their colour, and dissolve soap without leaving curds. They should be very

* By G. R. Burnell, C.E.

slightly affected by either the nitrate of baryta, the nitrate of silver, or the oxalate of ammonia, and when evaporated, the residuum should be very small. Potable waters, it appears, are improved by the presence of carbonic acid gas, which in the present state of the medical science is considered to assist the operation of digestion. MM. Dupasquier and Chossat appear to consider that the presence of a certain portion of the chloride of sodium, and particularly of the carbonate of lime, is essential in all waters intended for human consumption.

In the above indications of the qualities of water it is to be observed that the action upon the colour of vegetables and upon soap arises from the presence of the carbonate of lime, or from other modifications of that base. The oxalate of ammonia produces deposition of the sulphates of lime; the nitrate of silver deposes the chlorides; the nitrate of baryta the sulphates of other bases.

The temperature of water used by human beings is a condition of nearly as great hygienic importance as its chemical nature. The best water is that which has a constant temperature,—that is to say, compared with the atmosphere it should be warm in winter, cold in summer. Haller asserts that it is advisable not to use a water whose temperature corresponds too closely with the state of our own organs, and that when it is of a temperature below that of our body, it quenches thirst, not only by moistening, but also by changing the state of the organs. It follows, that a smaller quantity of cold water will suffice than either temperate or warm water, and it is very certain that the coolness even of a water, otherwise bad, will render it more agreeable than one which nevertheless may be of a far superior quality if it be warm.

Aeration is also an important quality of water destined for human consumption; the oxygen thus communicated forms, in fact, an essential element in its salubrity. The quantity of oxygen which can enter into combination with water differs according to the elevation of the source and the length of time during which the stream may have been exposed. According to Saussure, the proportion of air suspended in running water varies from 5 to 5·25 per cent. Boussingault considers it to be 3·5, but evidently the pressure to which the water is exposed must influence the precise proportion. In the Cordilleras, for instance, at a height of about 2½ miles above the sea, there does not exist a sufficient quantity of air in suspension in the waters to support life in fishes. Humboldt and Provençal make the proportion of air in river waters even less than that quoted above, for they state that it is only 0·0987 of the volume of the liquid; but at the same time it would appear from their researches that this air contains a much larger dose of oxygen than that of the atmosphere; in general the air suspended in water contains 32 per cent of oxygen. The presence of the air may be ascertained by the simple operation of boiling, when it will be given off in bubbles, or by mixing with the water a small dose of sulphate of iron to which a few drops of ammoniac are added. If this operation be carried on in a position sheltered from the atmosphere, and any air be present in the water, a white precipitate will be formed, passing subsequently to green and to a yellowish orange colour.

Potable water must be free from vegetable or animal matters: the least inconvenience attached to their presence arises from the deoxygenization of the air in suspension, and the decomposition of the extraneous matters which takes place rapidly under the conditions of contact with the air and the existence of moist heat, and renders the water putrid. The presence of these matters may be detected by chlorine solutions, or by an infusion of gallic acid; but they often entirely escape observation in chemical analysis, whilst it as frequently happens that waters notoriously unwholesome present traces of organised matter so feeble as hardly to be appreciable. A careful observation of the effects of any particular water upon human beings, or upon the animals using it, is therefore as essential as a chemical analysis. Indeed, organised life is a

far more delicate re-agent than any that can be inferred from the colour of a precipitate; its indications therefore must be attended to even more than the grosser indications of chemistry. Dr. Angus Smith, in addition, has remarked, that the waters kept in large towns contain a peculiar organic matter, and that they part with it in a variety of ways, particularly by their transformation into nitrates. He adds, that water, from whatever source it may be derived, cannot be kept for a long time in a state of purity, unless upon a very large scale, and that it is advisable to use it as soon as possible after it may have been collected or filtered.

Rain water collected in the open country, or at sea, a short time after the commencement of a shower (for the first drops that fall carry down the impurities in suspension in the lower strata of the atmosphere), is the purest which can be obtained. In storms it sometimes contains nitric acid; at all times it is aerated, but flat and insipid to the taste, and is likely to cause colics. For industrial operations it is, generally speaking, considered to be the best.

Snow water is without air, and usually deposits a small quantity of dust on being melted. Ice water is bright and pure, but difficult of digestion. The peculiar and loathsome disease called the goître is usually attributed to the use of dissolved snow; but the healthy state of the crews of Capt. Parry's ships during their long arctic voyages, when they had no other resource than the dissolved ice, would appear to show, that if proper precautions be taken, it may become a valuable source of supply under similar circumstances.

Spring water is considered by the public generally, and by most empirical writers, to be the most fitted for human consumption, whilst many scientific men prefer river waters. Absolute *à priori* opinions upon this subject are excessively dangerous, and it is possible that the error may be equal on both sides. Springs differ in their qualities according to the nature of the strata they traverse; chemical analysis and medical experience must therefore decide whether they be of a proper quality or not.

Rivers are produced by the confluence of streams and springs, and consequently near their sources their waters participate in the qualities of the latter. In their course, however, they acquire a degree of purity they may not have possessed at their origin, if they run upon a rocky or clean sandy bed, and do not receive the organised matters draining from the lands traversed. The assertion which it has lately been attempted to convert into a law, viz., that 'the nearer the source the purer the water,' is, therefore, only to be received with a reservation. Like all other attempts to dogmatise on subjects of natural history, it would be dangerous to admit the universality of the supposed principle; indeed, in the majority of cases spring waters are improved in quality by exposure to the air, if at the same time they flow with a certain velocity. They part with any excess of carbonic or sulphuric gases they may contain, they depose their earthy carbonates, they absorb oxygen, and if they should meet with other springs charged with ingredients different from their own, they may mutually purify themselves. But although the agitation and exposure to the atmosphere may facilitate the deposition of certain salts, there are others such as the sulphate of lime, the chloride of calcium and magnesium, which are retained much longer. Often when a confluence of two rivers takes place, the distinguishing elements of both of them may be traced for a considerable distance. The banks of the Seine furnish a remarkable instance of this fact; for some miles below the junction of that river with the Marne, on the left bank, calcareous salts predominate; on the right, the magnesian salts, associated with earthy matter brought down by the Marne, prevail. The quantity of solid matter in suspension in river water varies in almost every case. Thus, in 1834, Mr. Kerrisson found that the river Thames contained $\frac{1}{3217}$ of solid matter; the Seine is considered to hold $\frac{1}{20000}$; the waters of the

Garonne, at Bordeaux, are so charged with matter as not to be purified after standing ten days; the Rhine is stated to contain $\frac{1}{100}$ of solids in suspension in flood seasons, although the more accurate observations of Mr. L. Horner would only make it $\frac{1}{10000}$. In the tropical regions the proportion is even greater, for Major Rennel states that the Ganges near its embouchure contains $\frac{1}{4}$th of solid matter in suspension, and Sir G. Staunton estimated that the Yellow River, in China, brought down $\frac{1}{200}$ of earthy ingredients. Manfredi, the Italian hydrographer, calculated that the average proportion of sediment in all the running water on the globe, which reached the sea was $\frac{1}{175}$; but modern investigations shew that this estimate is greatly exaggerated.

The deposition of the earthy salts contained in spring water takes place in a very striking manner in the channels or pipes in which it may be conveyed. Sometimes this action is carried to such an extent that the capacity of the conduit is materially diminished. For instance, in the aqueduct passing over the Pont du Gard the sectional area is contracted by a deposition of carbonate of lime: in many cases in our own country the same effect is produced; and in others, where the waters contain the hydrous oxide of iron, the interior capacity of the pipe is diminished by a deposit of that material with remarkable rapidity. Waters of either of the descriptions alluded to would evidently be improved by a lengthened course over a clear rocky or sandy bed; but it is a matter of at least equal, if not of greater importance, that all contaminations from decaying vegetable or animal matter be excluded, and that the atmosphere with which they are in contact be pure.

Well waters, if only raised from shallow springs or in small quantities, are liable to become stagnant, deficient in aëration, and to take up any soluble salts existing either in the ground or in the masonry. In towns, wells appear to contain large proportions of the nitrates, and in London at least they are remarkably hard; at Manchester they are selenitic, but the presence of the nitrates appears to check the development of vegetable life, unless it be that of a peculiar fresh-water alga. In the construction of wells, it is advisable to use silicious materials as much as possible, and to employ the argillaceous cements: a precaution of still greater importance is to place the wells in such positions as to remove them from the influence of dung-pits, cess-pools, grave-yards, or other receptacles of decomposing organic matter. The distance through which the putrid waters from the latter are able to filtrate renders it advisable to adopt every possible precaution against their entry. The subject of wells will, however, be treated more in detail under that head.

The waters of large lakes are of a quality intermediate between those of rivers and of pools; they must, however, be always exposed to acquire, in variable proportions, —of course, according to their dimensions, their exposure to the wind, and the nature of the rocks upon which they repose,—the qualities of stagnant waters. Ponds and canals are necessarily still more affected by these qualities; marsh waters possess them to such an extent as to warrant us in laying down the absolute law that they should never be resorted to. Stagnant waters are for the most part saturated with gases arising from the decomposition of the vegetable and animal matters they may contain or receive, and the contact of the hydrogen gases with the sulphates turns the latter into fœtid sulphurets of the most repulsive and noxious description.

These remarks upon the nature of pond waters have a practical bearing upon a mode of collecting the rain-fall over particular districts, which has been lately brought before the public in a prominent manner, under the name of 'Gathering Grounds.' In that system, as it is necessary to store the excess of the winter rains to insure an average supply during summer droughts, it is necessary to form reservoirs of considerable capacity. It is indispensable, therefore, in order to insure a comparative degree of purity, that the water should be received into reservoirs constructed of

materials which are neither able to impart any soluble salts, or to develop any vegetation. The form of the reservoirs must be such that the lowering of the water-line should not leave broad belts of moistened earth or masonry; in fact, the sides should be as nearly as possible vertical. But even when these precautions have been observed, waters stored for any length of time part with their air, become deoxygenated, and allow any chemical reactions between the ingredients they may take up from the ground over which they flow to develop themselves under the most favourable conditions. In some of our East Indian Colonies it is often necessary to construct 'tanks,' for no streams or springs are to be met with. In such cases, the faces exposed to the water should be executed with silicious stones bedded in cement, and the tank must be covered. The geological configuration of the tropical regions may possibly justify the adoption of this tank system: but, and especially in our own country, it can only be exceptionally that it can be advisable to resort to the system of storing rain or surface waters, should any streams flow within a reasonable distance of the locality to be supplied. It cannot, however, be too often repeated, that Engineering is a science of expediency,—of the adaptation of means to the end. No absolute law can be laid down in any case, but every individual one must be regulated by the peculiar circumstances affecting it.

Should it ever be necessary to use stagnant water, it may be purified from its noxious gases by ebullition, and in the same manner the organic matters in suspension will be deposited. It should then be filtered through sand, or it would be preferable to pass it through pulverised charcoal. Air may be communicated by allowing the water to fall from a height; or, if only small quantities be operated upon, agitation or simple exposure to the atmosphere for a few hours will suffice. Habich states that stagnant water may be purified by mixing with it a compound of 1 part of quicklime and 2 of alum, or 4 of animal charcoal and 1 of alum, in the proportions of 1 of the compound, in volume, to 1000 of the water: and leaving them in contact for a night will usually be sufficient to attain the desired purification. It might be preferable to throw the pounded charcoal into the water overnight, and to add the alum on the next day.*

Engineering details of supply.

When a copious supply of water possessing the requisite sanitary qualities shall have been secured, there remains to be settled the means of conveying it to the place where it is to be consumed, and of distributing it from house to house. It rarely happens that the supply is to be met with in such positions as to satisfy all the conditions of a theoretically perfect distribution. The sources are situated either at a great distance from or at a lower level than the place where they are to be used, so that it is almost always necessary to conduct them from a great distance or to raise their waters artificially.

Volume of source.

The first operation required in all works connected with a distribution of water is to ascertain the volume which may be required within a definite space of time in the different seasons of the year, as also the possibility of any eventual modification in its quantity. If the source of supply decided upon, in consequence of the chemical analysis, be from springs, they should be carefully gauged; and, if possible, the observations should be extended over the number of years constituting the cycle of climatological changes in the locality. Should it not be possible to carry out these observations to the extent mentioned, it would be preferable to draw conclusions from the average working power of any mills, should such exist; because isolated gaugings

* At the Cape of Good Hope, where the frontier rivers are frequently impregnated with the soil from the mountains, being mixed with mud, equal to $\frac{1}{5}$th and $\frac{1}{6}$th of the volume, it was the practice to put a small lump of alum of about $\frac{1}{2}$ inch cube into two quarts of water, when after a few hours, it became fit to use.—*Editors.*

are as often likely to indicate a flow far below the average as they are at other times likely to indicate it in excess.

Modes of conducting supply.

The second operation is to settle the point to which the waters are to be conducted previously to the distribution to the respective tenements : and to establish between the source and the distribution a conduit whose section and inclination shall be sufficient to insure the delivery of the quantity required, should the water flow between the respective points by gravitation : or to provide the means of forcing the water to a higher level in case the point of supply be placed below that of distribution. It is desirable that the latter be placed at as great an elevation as possible, in order to facilitate the distribution into all parts of the district to be supplied, and to deliver the water at the most elevated positions therein.

Water may be conducted between the extreme points of the source either by means of open canals or by lines of pipes following an uninterrupted direction, but at the same time adapting themselves to all the inequalities of the ground. In the former, the water only receives upon its surface the pressure of the atmosphere, and its movement results simply from the inclination of the bed. In the latter, the water usually occupies the whole internal diameter of the pipe; it exerts upon its sides a pressure, which is the greater in proportion to the difference of level between the pipe and the source, or what is usually called the 'head,'—and it acquires a velocity, which, if all other things be equal, depends also upon the head.

Raising water.

Water may be raised by means of many different machines already noticed in the article on 'Water Meadows.' For all practical purposes, however, our attention may be confined to pumps, whether suction or forcing, which are set in motion by steam-engines or water-wheels.

Distribution.

The distribution into the respective parts of a town is effected by means of a series of mains and submains carrying it to the positions where the consumption will take place.

Modes of conducting supply.

When the source of supply is situated at a great distance, it would appear, from what has been before said, that it is decidedly better, so far as quality is concerned, to conduct the waters in open channels, than in either covered aqueducts or in pipes. But as there can be no absolute rule in engineering works, so in this particular instance circumstances may require that either of the latter methods should be employed in preference to that of open conduits. For instance, if the atmosphere of the locality through which the waters flow be contaminated from any natural or artificial cause, the effects consequent upon exposure to it will be injurious rather than beneficial. If the temperature be elevated, not only will the waters be rendered disagreeable as a beverage, but frequently they will be chemically deteriorated, and a serious evil will be encountered in the evaporation if open channels be used. In tropical climates, therefore, or near large manufacturing towns, covered conduits are necessary; in the open country of temperate climates they should be open. Such channels as the New River, near London, ought to be covered : the deteriorated quality of the water of the Croton Aqueduct would lead to the belief that the latter channel ought to have been open in the greater part of its transit.

Open channels.

If the water be not conducted in pipes, but in an open channel, the fall must be uniform in the whole length, and the inequalities of the ground must be overcome by means of embankments or bridge aqueducts, which may be occasionally of three stories in height. The ancient Romans have left some very remarkable works of this description, such as the aqueducts of Evora, Merida, Segovia, Nîmes, Metz, &c. The government of the Lower Empire did not neglect these works either, for the aqueducts near Constantinople are upon a colossal scale. In more modern times, the aqueducts of Spoletto, Genoa, Caserta, Lisbon, Marly, and Roquefavour, may be

cited, even if we leave out of consideration such works as the New River, the Canal de l'Ourc, and the Croton Aqueduct.

Pipe conduits.

If the water be conducted by a pipe constantly full to a certain extent, providing a sufficient head exist at the upper extremity, it may be made to overcome any difference of level, by descending one side of the hill and rising on the other, as in a reversed syphon. The Romans occasionally resorted to this manner of obviating the effects of deep valleys, but in consequence of their ignorance of metallurgic arts, their means of executing such syphons entailed too great an expense to allow of their frequent employment. A very remarkable instance of this kind of Roman construction is to be found in the aqueduct of Lyons.

Formula for open channels.

Should it be determined to lead the water to the point of distribution, supposed to be at a sufficient elevation to insure the house service by gravitation only, the dimensions of the channel will be ascertained by the formula already noticed in the article on 'River Navigation.'

$$Q = S\,v, \text{ from which we have } v = \frac{Q}{S}.$$

Q = the quantity discharged per second,
S = the section of the water-course,
v = the mean velocity of the discharge.

According to De Prony, the inclination I will be, $I = \frac{P}{S}(a\,v + b\,v^2)$.

P = the wet contour of the aqueduct,
a = a coefficient of 0·0000444,
b = a coefficient of 0·000309.

Eytelwein makes the coefficients respectively, $a = 000024$, and $b = 000365$. It appears that for small volumes the coefficients given by De Prony are the more correct, but that those of Eytelwein are more applicable to large rivers.

Calling the quotient of the transverse section of a water-course, S, by the wet contour, P, the mean radius, or R; it will be $R = \frac{S}{P}$; and the formula of De Prony gives by substituting for a and b their values as above,

$$R\,I = 0{\cdot}0000444\,v + 0{\cdot}000309\,v^2,$$

from which we may deduce

$$v = \sqrt{0{\cdot}005163 + 3233{\cdot}428\,R\,I} - 0{\cdot}07185,$$

or nearly

$$v = 56{\cdot}86\,\sqrt{R\,I} - 0{\cdot}072$$

From these formulæ, knowing the value of I and R, that of v may be ascertained; or equally, what ought to be the inclination I, so as to insure a velocity $v = \frac{Q}{S}$. The value of R depends upon that of the section S and the form of that section, which is much influenced by local circumstances. If the aqueduct be in wood or in masonry, the sides may be made vertical; and in order to reduce the wet contour to the lowest dimension, so as to present the smallest frictional area, it is advisable that the width should be equal to at least twice the depth. If it be in earth, the sides should be inclined, and the width vary from four to six times the depth of the water.

These formulæ are precisely identical with those used in settling the dimensions and fall of canals or derivations; but inasmuch as conduits for town supplies are usually executed in masonry, they can more easily be made to pass under-ground in headings, and the bridges they require need not be of such large dimensions as those for canals. The conduits in the former case are necessarily covered either by arches

or landings; in the latter the practice of engineers varies according to circumstances. The Roman aqueducts were made so as to insure their being 2 feet below the level of the ground; if in embankment, they were usually covered with about $2\frac{1}{2}$ feet of earth. In the Croton Aqueduct the depth of this covering is increased to about 4 feet; and unless the height of the top water-line exceed 25 to 30 feet above the lowest part of the valley, it is carried upon a solid wall of masonry.

Construction of conduits.

In the construction of the conduit care should be taken that the materials employed be of a nature which should not be likely to affect the qualities of the water, and that the most perfect impermeability should be attained. Silicious stones, fire-clay bricks, or decidedly argillaceous limestones, should be preferred to such as are able to furnish readily the bicarbonate or the sulphate of lime. Hydraulic limes (or better, Roman cement) alone should be used; but great care is required in the selection of this class of materials, because many of the most efficient cements are exposed to the serious inconvenience of giving out the salts (the nitrates or muriates) of soda. The Romans used an artificial cement composed of lime, sand, and pounded bricks, laid on in two thicknesses, the second of which was evidently worked up carefully with the hand-trowel. In many situations this process might be advantageously adopted at the present day.*

The dimensions of the different parts of conduits must depend so much upon the nature of the ground to be traversed, and the resistances which they may be required to offer, that it is dangerous to lay down any general rule. In subterraneous aqueducts it is usual to make the width in the clear about 3 feet 6 inches, with a height of about 7 feet, in order that they may be visited easily; but these limits must vary according to the quantity of water to be conveyed. If the foundation be good, it would not be necessary to make the floor more than from 13 to 14 inches thick, without including the layer of concrete beneath it; the side walls should be from 1 foot 10 inches to 2 feet 3 inches thick; and the arched covering about 14 inches thick at the key if the superincumbent weight be not very great. When the conduit is carried over valleys, the thickness of the solid sustaining masonry is made somewhat greater than the external dimensions of the aqueduct immediately below the floor, and a slight batter is given on both sides; and in bridge aqueducts a set-off is made at each tier of arches, should there be more than one.

The practice of the Romans in the construction of large bridge aqueducts is far more to be depended upon than the bold style of engineering introduced by Railway Engineers, especially in countries exposed to volcanic action. The openings they gave to their arches, when executed in ashlar, varied from 24 to 48 feet generally, although in their Pont du Gard the arches over the river have spans of 75 feet 8 inches. When executed in mixed ashlar and rubble, the spans were made from 18 to 36 feet; when in rubble cased with brickwork, from 12 to 24 feet. The thickness of the piers measured in the direction of the axis varies from $\frac{1}{5}$th of the span in the Pont du Gard to about $\frac{1}{4}$th in the aqueduct of Segovia, executed like the former, in ashlar. When the arches and piers were of brickwork or rough stones, the piers varied from $\frac{2}{3}$rds to $\frac{1}{2}$ of the spans. If there were several ranges of arches, the first from the ground was usually made $2\frac{1}{2}$ times its clear opening from the ground to the under-side of the key; the second about $\frac{1}{5}$th less in height, and the third $\frac{1}{5}$th less than the second. The space between the arcades was usually $\frac{1}{5}$th of the height of the first range under the key. Up to a total height of 84 feet the arcades were made of only one range; from 90 to 160 feet they were made in two; from 180 to 250 feet, in three ranges.

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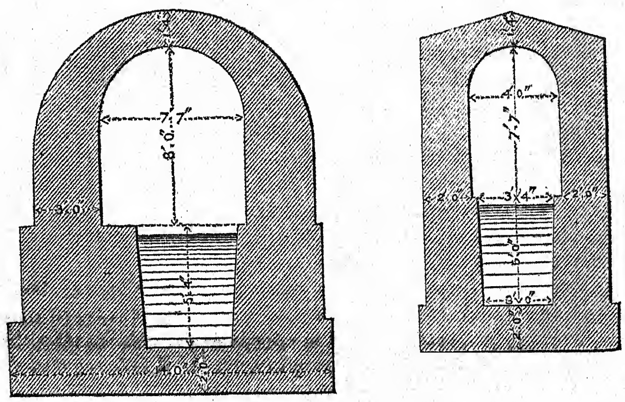
* This process is common in Sicily at this day.—*Editors.*

Small wells were formed at distances of about every 100 yards, to allow the deposition of any extraneous matters in suspension; visiting and air funnels were also placed from distance to distance.

In the Croton Aqueduct the principal details enumerated above were faithfully copied, and notwithstanding the criticisms of some modern writers, they may be still considered, in spite of some defects, to be those called for by the necessities of hot climates. In the Roman aqueducts aëration was partially secured by discharging the water from the conduit into large basins or castella. In the house distribution, however, the manners of the ancients gave rise to so different a system from our own, that it is probable that the fountains in every house would obviate the want of aëration in the aqueduct itself. The Croton Aqueduct is in this respect even more deficient than the ancient ones, insomuch that no method is adopted to supply the requisite quantity of air; and it is also to be observed that the system of forming immense artificial lakes at the head, as there executed, is objectionable, on account of the facilities it affords for the chemical actions upon organized matter. The Romans almost invariably resorted to springs whose flow was perennial, instead of storing the flood-waters upon the principles adopted by the American engineers.

The main feeder of the distributing pipes of Paris is a good example of a conduit in solid masonry. The larger one is about 1½ mile long, and has a total fall of 4 inches only in the length; the smaller one is a subsidiary branch into one of the most popular quarters, and is about 333 yards long.



Syphon bridges. In some cases where the depth of the valley is very great, and the number of arches required to overcome the difference of level becomes too considerable, bridge aqueducts have been replaced by syphon bridges. In these the pipes are made to follow the contours of the valleys, but any sudden irregularities are compensated for by a series of low arches, with a regular inclination upon the sides, and by an ordinary bridge in the bottom. On the summits of the respective hills are placed reservoirs, and the water descending from one will rise into the other, to a height corresponding with the head upon the pipes minus the loss arising from the friction, and any difference in the sectional area of the pipes from that of the conduit. The pipes forming the syphon may be either of lead or iron, the thickness being necessarily in proportion to the head upon them.

In the course of the Roman aqueduct leading the waters from the Mount Pila to Lyon is a very remarkable syphon bridge of this description. The valley itself is

about 2600 feet across, with a depth of 217 feet, but there is an arcade in the lower part reducing the length of the descending limb to 164 feet : that of the ascending limb is 142 feet 2 inches ; and the length of the arcade is about 460 feet. The pipes are of lead; for one-half of the descent they were $8\frac{3}{4}$ inches diameter, and $1\frac{1}{12}$th inch thick ; and for the remainder of the descent, along the level arcade, and for the first half of the ascending limb, they bifurcated into smaller pipes 6 inches in diameter ; at the last point they were re-united into pipes of 8 inches diameter, and so continued to the lower castellum. There were nine pipes communicating with the castella, and eighteen upon the bottom part of the syphon.

The aqueduct of Genoa has also in its course a syphon bridge, traversing the valley of the torrent Geivato, between the hills of Molassana and Pino. The horizontal distance between the two extremities is about 2193 feet 7 inches : the level part of the syphon is 164 feet below the upper reservoir, and the ascending limb has a perpendicular height of 139 feet 8 inches, making the loss of head 24 feet 4 inches. The pipes are of cast iron, in lengths varying from 2 feet 6 inches to 2 feet $10\frac{1}{2}$ inches ; their diameter is nearly $14\frac{5}{8}$ inches, their thickness about $\frac{3}{4}$ of an inch. This syphon is of modern date, it was erected in 1782. But the most important syphons ever executed are, perhaps, the one in the Manhattan Valley of the Croton Aqueduct, which has actually two pipes 5 feet in diameter, with a vertical depression of 102 feet, and the great pipes on the Rivington Pipe Water Works at Liverpool.

In works of this description it is necessary to provide means for discharging the air brought down by the water, which has a tendency to accumulate in the lower portion of the syphon. The ancients effected this object by means of an ascending pipe, rising from near the point where the change of direction is from the descending to the horizontal part, to a height somewhat above the castellum at the head. In modern syphons, air vessels which allow the escape of the air when it attains a certain pressure are used for this purpose.

Souterazici.

When valleys of great width are to be traversed, a series of syphons may sometimes be advantageously formed upon the principle of the Souterazici of the engineers of Lower Greece and of the Turkish empire. These consisted of pipes starting from an upper reservoir, descending to the bottom of the valleys, and rising again into a series of intermediate reservoirs, serving both as a means of discharging the air and as head reservoirs for the subsequent divisions of the syphon. The intermediate reservoirs are erected upon piers of masonry, at gradually diminishing elevations, on account of the loss of head occasioned by the friction of the bends. The distances apart of the piers were usually made about 500 or 1000 feet, and the difference of level between the water in two separate reservoirs was usually 4 inches.

Conduits in masonry, if forced to pass in the direction transversely to a line of hills, must occasionally be carried through them in tunnels. If the height of the hills does not exceed 28 feet, a syphon, set into action by filling both limbs from above, will carry the water over them ; but in such works greater precautions are necessary than in the descending syphons, because if any appreciable quantity of air accumulate in the upper part so as to occupy the bend, the action of the syphon will be stopped.

Proper velocity of water.

From numerous experiments it would appear that a velocity of 14 inches per second is indispensable to prevent the fermentation and decomposition of the organic matters contained in any water-course in warm weather. This limit should be adhered to as closely as possible, in order to secure the delivery of the water at the highest point in the position from which the distribution will take place.

Pipe conduits.

Should the quantity of water to be conveyed not be of sufficient importance to justify the construction of an open conduit in masonry with a uniform inclination, or should the water be derived from a source situated at a lower level than the distri-

buting reservoir, into which it is to be raised by mechanical power, it is necessary to employ pipes.

Pipes are occasionally of wood, of pottery, of cast or wrought iron, or of lead.

Wooden pipes are exposed to the serious objection that they communicate a disagreeable flavour to the water in many cases, and they are ill-adapted to the infinite modifications required in a house distribution.

Pottery pipes are economical, and often the most fitted to convey spring waters containing certain soluble salts. They are not able, however, to support a great pressure of water; and, generally speaking, they occasion a sufficient degree of friction to cause the earthy matters in suspension to deposit. It is found practically, moreover, that the roots of trees, which naturally absorb much water, will be attracted towards them from great distances, and that eventually they force their way through the mortar joints, and choke up the bore of the pipes. The use of cements attaining the hardness of the Portland cement might obviate this inconvenience to a certain extent.

Cast-iron pipes.

Pipes of cast iron are generally preferred, on account of their strength, of the facility with which they can be adapted to any change of direction, and of their durability. Some waters appear, however, to exercise a remarkable influence in developing their oxidation, thus giving rise to the formation of tubercles which diminish the sectional area of the pipes, and render frequent examination and cleansing necessary. This subject is still involved in considerable obscurity; but in a note inserted by M. Payen in the 'Annales des Ponts et Chaussées,' 1837, will be found a summary statement of the received opinions upon the subject. It appears from this, that aërated waters, slightly alkaline, are the most likely to produce the effect above mentioned. Grey cast iron is more exposed to it than whiter metal; and it appears that if the pipes be coated with a solution of hydraulic lime, or with linseed oil containing litharge, the formation of the tubercles is likely to be retarded. Chloride of sodium in small quantities exercises very great influence upon their development. Great precautions must be taken against the contraction and expansion of the metal.

Wrought-iron pipes.

Wrought-iron pipes have lately been introduced instead of cast-iron, the inner face being galvanized, and the outer face protected by a coating of asphalte. It has been found, however, that very serious inconvenience is attached to their use; because, if by any subsidence of the ground below them the superincumbent weight should compress the pipes, the sectional area would be diminished without any external indication to show where the interference with the flow existed. In fact, the elasticity of these pipes is an evil: cast iron would, under the circumstances supposed above, either not yield to the pressure, or, if the latter exceeded certain limits, it would break, and thus render apparent (by the flow of water) where the injury had taken place. Small pipes of wrought iron are, however, much used when there are no abrupt changes of direction.

Lead pipes.

Lead pipes of large dimensions are now seldom employed for the distribution of water, unless it be in the house services, as the pipes leading the water into houses are technically called. They can conveniently be drawn up to a diameter of 3 or 4 inches; beyond that, they are obliged to be formed by soldering a longitudinal joint, or by casting. In the latter case, the length can hardly exceed 10 feet, which would require nearly as many joints as for cast-iron pipes. Moreover, if the head of water be very great, the thickness would require to be proportionally increased. For house services lead pipes are the most convenient, on account of the ease with which they can be made to bend in any direction.

Lead is exposed to be acted upon by certain waters; but its effects, when so acted

upon, are far more prejudicial to health than those arising from the decomposition of iron pipes. There is still great obscurity about this important chemical question; but it would appear that there is some connection between the two actions, for the same waters which destroy lead by the formation of the carbonates, affect iron by giving rise to the formation of the hydrous oxides.

Formula for thickness of pipes.

The formula for ascertaining the thickness to be given to a cylindrical pipe exposed to a certain internal pressure is usually given as follows:

$$x = \frac{p\,r}{c - r}, \text{ in which}$$

p = the pressure per square inch;
r = the radius of the interior diameter;
c = the cohesive strength of the metal per square inch.

In practice, however, the dimensions obtained by the application of the formula are sometimes neglected, and they are made, especially in the smaller diameters, thicker than theory would require, on account of the difficulty of obtaining sound castings when the metal is of slight thickness. It is customary, also, to place two belts, of about 3 inches wide and $\frac{1}{2}$ an inch projection, in the length of the cast-iron pipes when the diameter is above 3 inches. Mr. Hawksley adopts the formula $x = 0{\cdot}18\sqrt{d}$ to ascertain the thickness, making it, in fact, about $\frac{1}{5}$ of the square root of the diameter.

Usual thickness.

The following Table gives the usual dimensions of cast-iron pipes, with their weights, up to 15 inches diameter.

Internal Diameter of Pipe.	No. of Belts per Pipe.	Length over Joint.		Net Length in work.		Weight per Pipe.			Thickness of Barrel.
in.		ft.	in.	ft.	in.	cwt.	qrs.	lbs.	in.
$1\frac{1}{2}$	...	4	9	4	6	0	1	0	0·288
2	...	6	4	6	0	0	1	21	0·3
$2\frac{1}{2}$	...	6	4	6	0	0	2	5	0·313
3	...	9	4	9	0	0	3	24	0·325
4	Two belts.	,,		,,		1	1	12	0·35
5	,,	,,		,,		1	3	6	0·375
6	,,	9	6	,,		2	1	4	0·4
7	,,	,,		,,		2	3	8	0·425
8	,,	,,		,,		3	1	15	0·45
9	,,	,,		,,		4	0	2	0·475
10	,,	,,		,,		4	2	21	0·5
11	,,	,,		,,		5	0	17	0·525
12	,,	,,		,,		6	1	0	0·55
13	,,	,,		,,		6	3	14	0·575
14	,,		8	,,		7	2	20	0·593
15	,,	,,		,,		8	1	13	0·612

The dimensions of lead pipes may be calculated by the formula $x = \frac{p\,r}{c - r}$. Mr. Jardine, of Edinburgh, found that a pipe $1\frac{1}{2}$ inch diameter and $\frac{1}{5}$th inch thick resisted a head of 1000 feet, but that it burst with a head of 1200. Another lead pipe 2 inches diameter, and also $\frac{1}{5}$th inch thick, resisted a head of 860 feet, but burst with a head of 1000 feet. The usual thickness of lead pipes in commerce is about $\frac{1}{4}$th of an inch, and the weights per foot run are as follows:

Thickness.	1 in.	$1\frac{1}{8}$ in.	$1\frac{1}{4}$ n.	$1\frac{3}{8}$ in.	$1\frac{1}{2}$ in.	$1\frac{5}{8}$ in.	$1\frac{3}{4}$ in.	2 in.
Weight . .	4·85	5·34	5·81	6·3	6·79	7·27	7·76	8·73

Belidor states that a large lead pipe 13 inches diameter and $\frac{13}{16}$ths thick will resist a pressure of three atmospheres. The pipes in the Gardens of Versailles are 2 feet $1\frac{3}{4}$ inch diameter and $1\frac{3}{8}$ inch thick.

Formulæ for movement in pipes.

In addition to the formula expressing the uniform movement in an open channel, before given, De Prony also ascertained one to express the movement in a regular cylindrical pipe ; it is as follows :

$$\frac{DJ}{4} = a\,v + b\,v^2 = 0{\cdot}0000173\,v + 0{\cdot}000348\,v^2,$$

rom which we derive

$$v = \sqrt{0{\cdot}0062 + 2871{\cdot}44\,\frac{DJ}{4}} - 0{\cdot}025,$$

or nearly $v = 53{\cdot}58\sqrt{\frac{DJ}{4}} - 0{\cdot}025$.

v = the mean uniform velocity ;
D = the inner diameter of the pipe ;
J = the inclination per mètre (or per yard) ;
a = a coefficient, made by De Prony 0·0000173, and by Eytelwein 0·0000222 ;
b = a coefficient, according to De Prony 0·000348, and by Eytelwein 0·000280.

When v is given, the discharge will be ascertained by the formula

$Q = S\,v = \frac{\pi D^2}{4} v$; in which $S = \frac{\pi D^2}{4}$ = the sectional area of the pipe.

Génieys gives a convenient formula applying to the case of a pipe of uniform diameter receiving its water from a reservoir at a high level, and discharging it constantly into another reservoir at a lower point. It is

$$Q = c\sqrt{\frac{H + \zeta - H'}{\lambda}\,D^5}, \text{ in which}$$

Q = the quantity to be discharged ; D = the diameter ;
λ = the length of the pipe ; ζ = the difference of level between the extreme orifices ;
H and H' = the heads upon these orifices respectively ;
c = a coefficient varying with the velocity of the water, as follows :

Velocity per second	2 in.	4 in.	8 in.	12 in.	16 in.	20 in.	78 in.	∞
c	15·06	17·22	18·83	19·50	19·84	20·07	20·79	21·043

The formula given in Beardmore's Tables is, however, more simple, and sufficiently accurate for practical purposes. It is given to ascertain the discharge when the diameter, the head, and the fall of the pipe are known, but of course everybody who is accustomed to the use of formulæ can ascertain the other terms of an equation if only one be unknown. The formula is $\frac{2{\cdot}356 \times \sqrt{d^5}}{\sqrt{\frac{l}{h}}}$, in which d = the diameter in feet, h = the head in feet, and l = the length also in feet. Mr. Beardmore gives another formula to be used when the head, length, and discharge are given to find the diameter ; it is $x = 0{\cdot}235\sqrt[5]{\frac{l \times q^2}{h}}$, in which l and h are as before, and q = the quantity to be discharged. He has calculated the results of the application of these formulæ, which will be found in his very valuable series of Tables.

Friction of bends.

A very important allowance has usually to be made in practice, on account of

the friction at the changes of direction, or even on account of the irregularities in laying the pipes. Navier states that the loss of head occasioned by a bend may be ascertained by the formula

$$p = \frac{u^2}{2g}\left(0{\cdot}0039\,\frac{1}{r} + 0{\cdot}0186\right)\frac{a}{r}.$$

p = the loss of head, owing to the bend ;
u = the mean velocity in the pipe ;
r = the radius of the axis of the bend ;
a = the development of the arc formed by the axis.

From this it would appear that p is proportional to the square of the mean velocity and to the length of the arc,—it is a function of the radius, and independent of the diameter ; and that p diminishes in proportion as r increases.

It is usual to make r of the following dimensions when side mains branch off from a leading one ;

Diameter. .	2 to 3 in.	3 to 4 in.	6 in.	8 in.	10 in. and upwards.
Radius. . . .	1 ft. 6 in.	1 ft. 8 in.	2 ft. 6 in.	3 ft. 6 in.	5 feet.

Beardmore gives as the formula upon which his Table of the Friction of Bends was calculated,

$$h = v^2 n \,\text{sine}^2\, 0{\cdot}003,$$

in which h = the theoretic loss of head ; v = the mean velocity ; n = the number of bends if their angles be equal ; or if they differ, then v will be multiplied by the sum of their sines, and the product by the coefficient 0·003. Beardmore also observes very justly, that the loss of head varies not only according to the size of the angle, but also to the volume to be carried ; and that the square root of the hydraulic mean depth will the most correctly express the variable term of resistance, and the loss of head should be divided by this quantity, to give the real resistance. According to him the formula for pipes becomes then, $h = \dfrac{v^2 n \,\text{sine}^2 0{\cdot}003}{\sqrt{\dfrac{d}{4}}}$: he has calculated a Table whose results are sufficiently accurate for any practical purposes, upon these data.

In vertical bends, the rate of delivery is further diminished by the collection of the air in the upper portion, and by the retardation of the flow occasioned by the fact that a definite proportion of the dynamical effect of the head is absorbed in overcoming the resistance of the column of water to be lifted on the lower side of the bend. To obviate these inconveniences, it is necessary, firstly, to place air-vessels over the upper parts of the bend ; and either to increase the diameter of the pipe before arriving at it, or to accelerate the flow in the portion above the bend.

Depth of pipes from surface and other precautions.

In positions where main feeding pipes are exposed to shocks or to the action of frost, it is necessary to cover them carefully with earth or sand. Usually they are laid about four feet from the surface. It may frequently be necessary to lay down a double line of pipes, with occasional communications, to insure the supply when any repairs are required. In pipe-conduits of great length, the head will exercise very different effects at the upper and lower extremities, so that it may frequently be advisable to vary the dimensions and thickness of the pipes. The form of the nozzles, or sluices, will often exercise a considerable influence upon the rate of flow,—and in fine, there are so many disturbing causes likely to interfere with the successful action

of such pipe-conduits, that it is impossible to dwell too strongly upon the necessity for studying their most unimportant details.

Reservoirs.

Hitherto we have only considered the case of a supply obtained from perennial springs at sufficient height to allow the water to flow by gravitation. But in the first place, there is almost always a great variation in the rate of supply by the springs, and in the consumption, which renders it necessary to equalise the flow by storing the excess of some seasons of the year against the want of others. In order to prevent the water thus stored in the reservoirs from becoming stagnant, it is advisable that they should be traversed by a running stream. The sides and bottom should be, as before said, in masonry, or of some material which would not be likely to contain the soluble salts; and if near towns, or in countries where the heat is great, they should be covered over, if that course could be adopted within any reasonable limits of economy, because the difference in the cost of covered and open reservoirs is enormous. Open reservoirs for water supply may be constructed at an average rate of £600 per million gallons in the greater number of localities in our own country; the only large covered one erected of late years for that purpose cost £4000 per million gallons. It must then be a question to be considered whether the extra expense be absolutely required.

The dimensions of the retaining walls of these reservoirs will be ascertained by the rules already given. A horizontal circular section is not only the most economical, insomuch as it contains the greatest surface within a given development, but also because its form is the most fitted to resist the thrust of the earth, when the reservoir is to be sunk in the ground. The floor of these reservoirs must be inclined towards a scouring or cleansing pit, and in addition to the induction and eduction pipes, it must have a pipe at the bottom of the cleansing pit, to be closed by a valve, and an overflow pipe. It is advisable also to establish a communication between the induction and the eduction pipe, in case any repairs should be wanted in the reservoir.

The capacity of what may be called 'compensation reservoirs' must of course depend upon the variations in the supply,—in fact, according to whether they be fed by shallow or deep-seated springs, or by the collection of surface waters, and also to the rain-fall of the district. The latter is very variable, not only according to the seasons of the year and the latitude, but also according to the elevation of the particular locality, so much so as to render it dangerous to lay down any *à priori* rule. Experience in our own country has, however, shewn that a supply equal to six months' consumption is required to be stored in the wet season, to insure the means of an undiminished distribution in dry weather, whenever the water is collected from the surface. It is also very questionable whether, on the average of a great number of years, it be possible to depend upon obtaining more than ⅓th of the rainfall in any country exposed to long intervals of dry weather, however well the drainage may be performed. The very remarkable works executed by Mr. Thom at Greenock were designed so as to store six months' supply, even in the comparatively very wet district of the Western Highlands of Scotland. The results obtained in the several canal reservoirs confirm Mr. Thom's precaution.

It may happen, however, that although the yield of the springs from which the supply may be derived may be variable, they may yet possess a degree of constancy in their flow essentially different from the rain-fall. Thus, if the streams be given off from a geological formation of great thickness and with a great capacity for water, it will become to a variable extent, according to the circumstances of the case, a natural reservoir. Long continued observations are therefore required to ascertain the extreme variations; for it is to be observed that as water-works are designed to insure a supply

under the most unfavourable circumstances, it is more necessary to know the minimum yield of the source of the supply than the average. In England, the average cycle of the seasons is of about seventeen years' duration ; no gaugings of streams, then, are worthy of notice, unless they extend over that length of time. The different conditions of the permeability of the water-bearing stratum will also so far affect the rate at which the rain water can reach the springs, and the proportions of the water passed into the earth or evaporated from the surface, that it becomes even more impossible to reason *à priori* on the subject of springs than it is upon that of the rain-fall.

Methods to be adopted if the supply be at a low level.

It very frequently happens that large centres of population are seated upon the banks of rivers whose waters are perfectly fresh, whilst at the same time no source of sufficient abundance can be found at an elevation such as to allow of its distribution by gravitation. London, Paris, Philadelphia, and numerous other cities, are in this position, and it becomes then necessary to raise water by artificial means. In the large quantities required for a town consumption, the choice of the mechanical powers is narrowed to either water-power or steam-power, and local circumstances must always decide which should be adopted. Wherever it is possible to obtain sufficient power from a stream, there can be no doubt but that a water-wheel will be the most economical ; and in such cases as the town of Richmond in Virginia, Philadelphia, and Toulouse, it has been successfully applied. But in other cases, either from the interference of tides, from the irregularity of the flow in summer, or the ice in winter, steam-power is indispensable ; and, in fact, the improvements in the steam engine, combined with the diminished price of coals, have led in most cases to the substitution of steam-power for water-power.

Engine-power.

Engineers at the present day appear to be agreed upon this point, that when the power of the engine required to raise the water exceeds 20 to 25 horses, the Cornish pumping-engine is the most advantageous. Below that power the first cost of the engine becomes comparatively so much increased that it is preferable to employ a more direct-acting engine. The economy of working Cornish engines, moreover, hardly exists when they are small.

In the article upon Water Meadows (*ante*), in Mr. Wicksteed's account of the East London Water-Works, his papers on the Cornish Engine, and in Mr. Poole's valuable treatise on the latter subject, will be found more copious and useful information. The reader is also referred to Mr. Hawksley's evidence before several of the late Parliamentary Committees, to the account of the Public Works of America, and to D'Aubuisson's account of the Water-Works of Toulouse, for much interesting and practical matter connected with the raising of water.

The power required either for a steam or water-wheel pumping establishment, is ascertained by calculating the horse-power upon the basis of 33,000lbs. lifted one foot high per minute, and the resistance to be overcome by multiplying the number of gallons to be raised per minute by the dead lift, plus an allowance for friction, which is usually taken at 12 feet per mile, unless there should be any important vertical bends.

Settling reservoirs.

Whatever be the motive power adopted, it is almost always necessary, when the source of supply is a large river, to form settling reservoirs, in which the waters may deposit any matters they may contain in suspension, and also very frequently to construct filters for the greater purification of the waters. The dimensions of the settling reservoirs must depend to a great extent upon the greater or lesser degree of purity of the waters ; those of the filters depend upon, firstly, the mode of filtration adopted ; and secondly, upon the head of water acting upon the medium. Three days' supply is the minimum which ought to be admitted for the former : the rate of filtration varies from 75 to 200 gallons per foot superficial, per day, of the surface of the filters.

Filters.

In the settling reservoirs the effect produced upon the water must principally be mechanical, for it rarely happens that the water is kept long enough in them to allow of any efficient chemical action. In the filters the action may be either chemical or mechanical, but the expense attending the former is so great that it is hardly possible to develop it upon the scale required for a town supply. Hitherto, no ingredient has been discovered which possesses the disinfectant properties of the animal charcoal; but as it is necessary that the water to be filtered through it should previously have been cleared from the grosser particles in suspension by passing through a coarser description of filter, and that subsequently the water should again pass through some other filtering medium to insure its freedom from any particles of charcoal, we may safely consider that so complicated a process is beyond the reach of the public purse. A supply taken from the most perfect mechanical filter with as great rapidity as the latter can yield it, will in almost every case satisfy, not only the public demands, but also the real exigencies of the case.

There are several kinds of mechanical filters, of which the system adopted by Mr. Thom, at Paisley, that of the Chelsea Water-Works, that used at Nottingham and Toulouse, and the recent application of filtering slabs, whether natural or artificial, are the most important. Of these, the system used at Nottingham and Toulouse is the most economical when the bed of the river is formed of materials suitable to its application. It consists in the construction of filter-tunnels in the sand upon the banks; the water becomes purified by the fact of the adventitious matter being retained in the bed of the river, from which it is washed away by the action of the stream. If, however, the river carry down much clay, such tunnels will become choked in a very short time; if the sands contain any salts of iron, lime, or nitre, the water will be affected by them. It rarely happens that rivers roll upon beds of pure silicious sand, and even when this is the case, Dr. Clark's objections are still valid. He noticed, that near Glasgow, where many of these filters are in use, springs often rise into them from below, and bring waters of very different qualities. The level of the tunnels being fixed, whilst that of the water varies according to the state of the river, the rate of filtration must vary also, and in summer, when the consumption would naturally be the greatest, the yield would be the least. These filter-tunnels also must be exceedingly difficult to clean on account of the very nature of the materials, and their application must for the above reasons be confined to such localities as present the peculiar geological characteristics stated to be requisite.

The filter described by Mr. Thom as having been executed by him at Paisley appears to be the most theoretically perfect, inasmuch as from the fact that the last stratum of the filtering medium traversed is composed of a mixture of sand and charcoal, the operation must be, to a certain extent, chemical as well as mechanical. The system may be described as follows, nearly in the words of Mr. Thom: "The site of the filters is on a level piece of ground, excavated to the depth of 6 or 8 feet, with impermeable retaining walls and bottom. The whole of this bottom is divided into drains 1 foot wide by 5 inches deep, by means of fire-bricks laid on edge, and covered with flat tiles perforated with numerous small holes, like those used in malt-kilns. The perforated tiles are covered to the depth of 1 inch with clean gravel, about $\frac{3}{10}$ inches in diameter; this is followed by five other layers of gravel, each of the same depth, and each succeeding layer a little finer than the preceding one, the last being coarse sand. Over this very clean, sharp, fine sand, 2 feet deep, is placed, and about 6 or 8 inches of this fine sand, near the top, is mixed with animal charcoal." Some details connected with the overflow and the discharge-pipe, which will be found in Mr. Thom's description, complete its arrangement.

Mr. Thom made some observations upon the effects of the substitution of the

amygdaloidal rocks found near Paisley for the animal charcoal, which confirm the theory propounded by Professor Way upon the chemical action of certain soils. It was noticed that the amygdaloids were capable of removing traces of peat nearly as effectually as the charcoal ; animal matter also was separated by them. There is little reason to doubt but that the affinity between the silicate of alumina and the vegetable and animal matters in combination with the water is sufficient to cause these to leave the latter and to form new compounds with the silicate of alumina, which is the base of the amygdaloids. Professor Way noticed that clay, a hydro-silicate of alumina, acted in a similar manner, and Mr. Hassall arrived at the conclusion that both animal charcoal and mild strong clay are perfect with respect to their power of retaining the solid matters, dead or living, found in every description of water. Mr. Hassall also found, on the application of tests, that neither of those substances shewed any trace of sulphuretted hydrogen. However, this branch of chemical inquiry is still in a state of considerable uncertainty, and the means of removing with equal facility any excess of the bicarbonates, and the sulphates, of lime are still to be discovered.

The Chelsea filters are established upon a plan which is, perhaps, the most universally applicable, because the materials employed are found almost everywhere. Mr. Quick describes them as follows :—"The process of cleansing consists of a series of reservoirs of subsidence,—large open reservoirs between 4 and 5 acres in area, and 13 feet 6 inches deep, faced with gravel. These reservoirs have an invert of brick about 6 feet wide, and 3 feet 6 inches deep, laid in cement. The depositing reservoirs are made to hold four days' supply, and the filters placed by the side of them are composed of—1stly, coarse gravel, about 1 foot deep : 2ndly, a stratum of rough screened gravel, about 9 inches deep : 3rdly, a stratum of fine screened gravel, about 6 inches deep : 4thly, fine gravel, 9 inches deep : 5thly, fine washed river-sand, about 3 feet 6 inches deep. The water permeates these materials, and is drawn off by means of brick tunnels to the well of the pumping engine." The objection to these filters is, that they require a large surface and a considerable amount of earth-work, for, in addition to the depth of the sand and tunnels, it is necessary to have a certain depth of water upon them to act as a head. It is upon this account that it appears more than probable that considerable advantage would result from the substitution of filtering slabs for the layers of sand and gravel. There are many natural stones able to perform this office, such as the lighter and more scoriaceous volcanic rocks, some of the coralline limestones, and where these do not exist recourse may be had to Ransome's process, by which a porous sandstone can be made of any degree of coarseness or fineness required. All these stone filters are, however, necessarily exposed to be choked by the matters they separate, and precisely in the proportion of the perfection of their action. It is therefore necessary to protect their faces by a thin layer of sand, to be removed as often as is required.

Service reservoirs.

It was formerly the universal practice, after the water had been purified either by deposition or filtration, to raise it into reservoirs called 'service reservoirs,' placed at sufficient altitudes to allow the mains to be filled by gravitation. Of late years, however, a system has been introduced by which the water is pumped directly into the mains, and the excess, beyond the quantity drawn off for household purposes, passes on into the service reservoirs, which become under this system, in fact, regulating reservoirs, for their use is to store a sufficient supply for the period when the engines are not at work, and to provide against any minor accident. The principal danger attending this system arises from the frequent hydraulic shocks to which the pipes must be subjected by the opening and shutting of the house services ; but this may be obviated to a great extent by laying secondary mains, called riders, near the

leading ones, upon which the house services would be raised. Especial care must also be taken that the movement of the water, as it leaves the air-vessel of the engine, be as regular as possible. In spite of all these precautions, however, the flow towards the upper end of the mains must be exposed to fluctuations of a very unequal nature, especially when the pipes are always under charge, and the consumption takes place directly from them, on what is called the constant delivery system. Experience alone can decide upon the value of this new system.

The terms *constant* and *intermittent* supply have reference to the details of house service, to which we shall have occasion to allude in our notice of that portion of the subject.

Stand pipes.

In some cases, whatever be the manner of feeding the distributing mains, the water is raised, immediately after it leaves the air-vessel of the engine, over a stand pipe, or a vertical pipe sufficiently lofty to form a head able to discharge the water into the reservoir; the head must then be equal to the dead lift, and, in addition, be such as to overcome the friction on the road. At the East London Water-Works a great portion of the district used to be supplied by the stand pipe without the intervention of any reservoir; but this course is objectionable on the score that the engines are forced to raise the largest quantity of water which may be required in any given period of the day. They must therefore be of a power equivalent to the greatest, not to the average consumption of water in the district. A considerable portion of the steam-power will thus be unemployed during great part of the day, or, in other words, the engines will require to be more powerful than they would be if a service reservoir were used. The determining motive with respect to the use of stand pipes must be economy; for in many positions, as in the larger part of the East London district, a reservoir at sufficient altitude could only be constructed at a great cost. At the present day the steam pumping engine has been so much improved, and rendered in fact so automatic, that both stand pipes and service reservoirs have been dispensed with in the East London and the Kent Water-Works.

The dimensions of the service reservoir will necessarily be regulated, firstly, by the amount of the consumption, and secondly, by the nature and power of the steam engine. If the latter be of a description liable to interruptions in its action, or if the source of supply be exposed to irregularities, as in the case of a tidal river, or of one in which freshets occur, it is necessary to make the service reservoir of a capacity sufficient to insure the continuity of the flow during the periods of interruption. Should the configuration of the country be such as to render its construction easy and economical, it may be advisable to make it sufficiently large to hold about three days' supply in climates analogous to those of the South of England. But there is always something objectionable in keeping water in a stagnant pool, especially near a large town. It must be exposed to be affected by the impurities in the atmosphere, unless covered; and the expense of covering such reservoirs is so enormous as to preclude their use on an extensive scale, unless in certain very exceptional cases. In the greatest number of instances it will be found sufficient to make the service reservoir of adequate capacity to hold water enough to supply the consumption during the hours that the engine may not be at work, or to enable it to raise the water by an equable effort during the working hours. For this purpose a reservoir able to hold one-quarter of a day's supply will be all that is usually required.

It will be necessary, in case the reservoir be made upon this principle, to provide duplicate engines, or, at least, to have a sufficient number of duplicate parts in constant readiness to be enabled to repair any accident at the slightest notice. The supply will be to a certain extent liable to be interrupted; but, on the other hand, reservoirs of dimensions so ascertained could usually be covered with economy.

In many French towns, the water is raised into a tank situated immediately above the engines, the tanks serving, in fact, as the upper portion of a stand pipe, as an air-vessel, to discharge any air raised with the water, and, at the same time, as a distributing reservoir. Over a water-wheel, as at Toulouse, this arrangement may succeed, provided that the machinery be of a nature not exposed to accidents or to require frequent repairs. But unless the tank be made of considerable dimensions, such as would be required to render it a service reservoir regulating the flow, evidently the mains could only be charged so long as the machinery was working. In England and in America, the practice hitherto has been to establish large open-service reservoirs, but of late the more economical method of using smaller regulating, covered, reservoirs has become more general. In this particular detail, as in all others connected with engineering, it must again be borne in mind that no absolute rule can be laid down. Local circumstances must eventually decide what system should be adopted, so as to secure the most efficient supply at the least cost.

House or municipal distribution.

The municipal distribution of water may be effected in various manners, according to the habits of the population to be supplied, and to the influence of climate upon such habits.

In England, and also in the Northern States of America, the distribution is usually effected from house to house; on the Continent, and generally in warm climates, large quantities of water are discharged by monumental fountains, or are made to form rills in the channels of the streets, whilst house services are comparatively unknown. House services, again, may be either at high or low pressure; or the supply may be either constant or intermittent in its mode of delivery. As the system adopted upon the Continent is the most simple, and the most adapted to the habits of the population of our Colonies, it will be the first we shall examine, especially as the others differ from it merely in questions of working detail.

The ancient water-works upon the Continent, like many in our own country, distributed the water by means of wooden or pottery pipes, but in almost all cases cast iron has been substituted of late years for the principal pipes, and the smaller ones have been made of lead.

The formula which is applicable to the movement of water in a pipe passing from one reservoir to another ceases to be so when there is a series of side branches or of mains deriving the water reciprocally from one another. There is an important modification produced by the friction of the junctions and by the constant changes in the effective head, owing to the opening of the distributing pipes. During the course of the distribution, necessarily a difference will occur in the quantity to be discharged, owing to a portion being withdrawn for the branch pipes. It becomes requisite then to diminish the mains in the latter part of their course; but it must be borne in mind that up to a certain point it is economical to employ pipes of the same dimension throughout, for the cost of models may exceed the saving on the metal of the pipes. This question of detail, like all others, must be resolved by comparative estimates.

It is necessary, before deciding upon the dimension of a main pipe, to ascertain not only the existing demand it may be required to satisfy, but also the eventual extension of the demand, either by an increase of population or by the establishment of new factories.

In an isolated pipe receiving water from a reservoir at a higher level and discharging it at a lower one, the discharge may be calculated by the formula given above (p. 754).

$$Q = c\sqrt{\frac{H + \zeta - H'}{\lambda}\,D^5}, \text{ in which}$$

Q = the quantity discharged per second ;
λ = the length of the pipe ;
D = the diameter ;
ζ = the difference of level between the extreme orifices ;
H and H′ = the heads upon these orifices.
c = the coefficient derived from the Table.

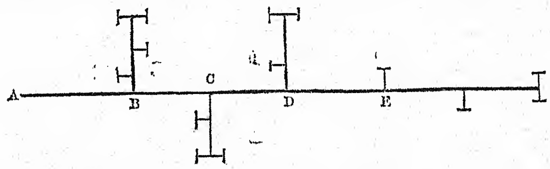
But, in a distribution, the water meets with several resistances, which tend to diminish Q : they may be stated as follows : 1, the usual friction upon the sides of the pipe must be allowed for ; 2, the effect of bends must be calculated ; 3, the retardation of the flow arising from the change of direction from the main to the submain, or to the branch pipe, must be taken into account ; 4, the species of gurgitation at every junction will also serve to diminish the yield.

The manner of calculating the two first resistances has been shewn. As to the third, it may be calculated upon the principle that when a fluid in movement in a pipe passes into a side branch, forming with the main an angle i, the velocity v, leaving out of account the other forces acting upon it, will only be $v \cos i$. As it is usual to make the seat of such branches at right angles to the main, the effect produced is to destroy any advantage arising from the velocity in the main, and to reduce the head merely to that existing in the latter at the point of junction of the branch.

MM. Mallet and Génieys tried some experiments to ascertain the effect of the fourth-named resistance, or the gurgitation, from which it would appear that the loss of head it occasioned was equal to twice the height due to the velocity of the water in the branch pipe.

Illustrations of mode of calculating sizes of delivery pipes.

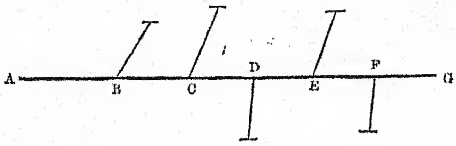
1. Practically, the following illustrations, given in Claudel's 'Formules à l'Usage des Ingénieurs,' of the manner of calculating the distribution in towns, will be found



to be sufficient to serve as models. Let it be proposed, firstly, to supply a district by means of a pipe of an uniform diameter throughout its length, and discharging the water at certain points by means of stand pipes constantly flowing in a similar manner to the 'borne fontaines' of Paris.

The diameter of the pipe must be such that the head should be sufficient at each opening to deliver the water at a few inches above the point of discharge. The diameter is ascertained by supposing it to be of any definite dimension ; the loss of head is calculated for the distance between A and B, and the effective head at B is thus determined by deducting the loss from the initial head ; this effective head must be sufficient to insure the delivery of the water at the orifices upon B. The loss of head between B and C is ascertained in a similar manner, observing that the volume discharged by the main will be diminished by the quantity withdrawn at B. This loss of head, deducted from the real effective head previously determined for B, will give the effective head at C, which, as before, must suffice to supply the orifices upon that submain. Proceeding in this manner with the branches D and E, it will be found whether the head existing at the separate branches will be sufficient to insure the discharge of water at the several orifices. If this head should not be sufficient, it will be necessary to try a larger diameter ; if it be in excess, a smaller one must be adopted.

2. Let it be proposed to determine the diameter of a pipe receiving water from both ends, and supplying in its course certain orifices able to discharge definite

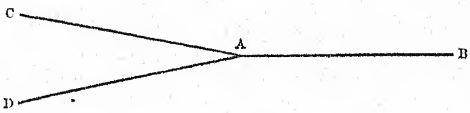


quantities. In such a case the orifices are supplied, some entirely from A, and some entirely from G, and it may happen that one of them, D, will receive its supply partially from the one or the other.

The diameter of the main in either of the parts D A and D G must be such that the head at the entry of D should be the same from either side. It is necessary to ascertain it by trial, as in the previous instance, and for this purpose some diameter is assigned to both D A and D G; after deducting the loss of head occasioned upon either of them by the branches B, C, E, and F, the remaining effective heads upon the respective portions of the main at D will be determined. Should they not be equal, one or both of them must be altered, as the results obtained may indicate.

3. When the distribution takes place by means of a conduit of different diameters, it will be found that the system indicated in the first illustration will satisfy the required conditions; because the diameters of the pipes are constant between two successive openings, and the rate of delivery is also uniform between them. It is necessary, however, in calculating the loss of head to allow for the difference of diameter in the pipes.

4. Should the supply main derive its waters from two pipes whose delivery is known, and should it be desired to determine the diameter of the pipe A B, so as to insure a particular distribution upon its length, the course to be followed would be as



follows: a certain diameter is assigned to A B, and as its discharge is known, and the difference of level between A and B is also supposed to be known, the effective head at A necessary to insure these conditions will easily be obtained. If, then, the diameters of A and B be supposed, as the volume to be supplied by them is known, it is easy to calculate the loss of head upon each of them, from the initial heads at C and D, so as to arrive at the effective head produced by them at A. This head should be the same for both pipes, and equal to that required to secure the delivery already supposed to take place between A and B. If the respective diameters should not be such as to insure these conditions, they must be modified.

If the supply by the two conduits C A and D A were not fixed previously, the quantity to be furnished by them might be made to vary as well as the diameters of the pipes, but of course always within the limits of the discharge by means of A B. Under all circumstances, the head at A must be the same for the two conduits, and be sufficient to produce a satisfactory flow in the part between A and B.

Description of a continental distribution.

Passing from these theoretical considerations, we may dwell in detail upon the system of distribution adopted in Paris as a good illustration of the best of the very imperfect town supplies executed by Continental Engineers.

The supply is derived from five sources: the spring waters of St. Gervais and

Belleville; the springs brought into the town by the Aqueduct of Arceuil; the waters pumped from the Seine directly, either by a water-mill upon one of the bridges, or by a steam engine at Chaillot; the waters brought in by the navigable Canal de l'Ourc; and, lastly, from the Artesian well at Grenelle. From these different sources, a total quantity of about 24½ million gallons per day is brought into Paris, or above 20 gallons per head, if the population be considered to be about 1,200,000.*

Of these sources the most important is the Canal de l'Ourc, which supplies four-fifths of the total consumption. It arrives in Paris at a height of about 166 feet above the summer level of the Seine, and is thus able to distribute its waters by gravitation into almost every quarter of the town. An aqueduct, of which we have already given a sketch, is continued round the hills, forming a kind of amphitheatre on the north side of the town, and a smaller aqueduct is constructed upon a spur projecting into the quarter of St. Laurent. The mains are led from these aqueducts to a series of reservoirs in the most commanding positions in the different parts of the town, five in number, of an average capacity of 1,540,000 gallons each, in round numbers.

During the day-time, the water, instead of passing from the canal to the reservoirs, is diverted into the submains and allowed to flow from a series of small stand pipes into the gutters by the side of the footpaths; at night, these stand pipes are closed, and the water passes into the reservoirs, where it is stored for the supply of the parts of the town not immediately upon the line of mains. These stand pipes are called '*borne fontaines*,' and are entirely at the cost of the municipality. They flow at three separate intervals during the twenty-four hours of an hour each, or during three hours per day, and discharge about 650 gallons per day in the summer months; they only play two hours per day in winter. As in Paris the custom prevails of discharging all household rubbish, such as we consign to the dust-bin, into the street, and as near the gutter as possible, this mode of distribution is necessary to clear them; and at the same time the flow of the water cools the air in the close streets, from which the sun's rays are reverberated with singular intensity on account of the materials used in the construction of the houses. Up to 1845, no less than 1600 of these fountains existed, and they were placed at a distance of about 410 feet apart, upon the mains; and wherever it was practicable, they were placed at the culminating point of a gutter, so that the water might flow in two directions, and enter into the sewers as rapidly as possible.

In addition to the 'borne fontaines,' from which anybody is allowed to draw water, there are other fountains called 'fontaines banales,' from which the public is entitled to take water gratuitously, as are also the water-carriers who sell the water by pails. Other distributions, called 'fontaines marchandes,' often provided with charcoal filters, furnish the water-carriers who employ carts. Stand pipes to supply carts for watering the streets in summer, are also placed at average distances of about 1640 feet apart. These are used, on the average, 135 days per annum, and it is found that about 1½ pint per yard superficial will suffice to insure a satisfactory service, which in summer must take place twice a day. The system of the hose and jet, lately so much praised in England, has been tried and found to be far too irregular in its effects, besides annoying the passengers.

Distributions for trade purposes and for household consumption also take place,

* The population of Paris is now 1,600,000; but the quantity of water has not materially changed since the above was written. There are, however, great *projects* under discussion for an increase of the supply.—G. R. B.

but the latter are not under such condition of pressure as to carry the water to a point above the level of the first floor.

Ornamental fountains are placed in conspicuous positions, with a view also to secure as great hygienic effects as possible; from some of these the public and small water-carriers are allowed to draw water gratuitously.

Such, with a few modifications, principally in the manner of bringing the supply from the source to the point of distribution, is the system adopted in France, Spain, and Italy. It is very defective, according to our notions of domestic comfort, and certainly not such as to induce habits of cleanliness; for moderate as the charge upon the sale of the water may be, the necessity of paying, as it were, for every pailful used, must check the copious employment we are accustomed to. The amount of supply, stated to be 20 gallons per individual, above quoted for Paris, is also very fallacious, so far as the real personal consumption is concerned; for more than half of the quantity brought in is used for the 'borne fontaines' and the ornamental waters, and from the remainder it is necessary still further to deduct the quantity used for trade purposes.

Quantities used for various purposes.

It may be interesting to state the quantity of water consumed for some private purposes, which has been observed by French engineers.

A bath requires on the average	75 gallons.
A horse requires per day	16·5 ,,
A two-wheel private carriage per day	8·8 ,,
A four-wheel ,, ,, ,, ...	16·5 ,,
Each individual per day	4·4 ,,
Every yard superficial of garden ground per day . .	0·33 ,,
Every yard superficial of railway, per service . . .	0·22 ,,

The quantity allowed for human consumption is small in comparison with our English notions; but it would appear that in reality our town population, even in the driest summers, does not consume more than about 8 gallons per head per day of 24 hours.

English systems of distribution.

Low service.

In our own country, until within a few years, the greater number of towns were supplied with water at low pressure, and at stated intervals, excepting when local circumstances allowed a constant distribution by gravitation. In these cases the water was brought into the houses by lead pipes, branching upon the mains in the street, and leading the water into cisterns, where it was stored until used, or from which it was raised by force-pumps to any greater altitude the householder might require. Improved domestic habits have rendered it so necessary to command a supply even in the highest parts of the houses, that it is found now to be more economical to obtain it by a general system, by which the water arrives under sufficient pressure to insure its delivery at such points. The extra height to which the water is thus carried being usually overcome by steam-power, necessarily gives rise to an increased outlay, and thence the distinction and the difference of charge for a supply upon what are technically called the high or low service. In London the low service is usually understood to mean that the water is delivered at heights varying from 6 to 9 feet above the roadway; the high service is usually comprehended within a height of 30 feet above the same level, and includes every delivery above the 6 or 9 feet of the particular district.

High service.

Constant supply.

At Nottingham and in some other towns a system has lately been introduced, under which the mains and service pipes are kept always full, and water can be drawn in any quantity: the latter can discharge at all times of the day or night,—this is called the *constant* system, and it is principally to that able engineer, Mr. Hawksley, that

the public is indebted for the amelioration it produces. It will at once be perceived that with such a distribution there can be no occasion for cisterns, and that the water will, with a few precautions, be kept in a state of purity which it is impossible to attain when stored in those receptacles.

For the intermittent supply, the formulæ and the observations already given or made, with reference to the continental manner of distributing water, will apply; for under it the only real question to be solved is, how to supply a given district by means of pipes, delivering water at stated periods, by services flowing at certain definite periods? On the constant supply, however, the question is more complicated, owing to the irregularity of the consumption. This is stated by Mr. Marten ('Report of the Board of Health on Water Supply,' Appendix 2, p. 67) to vary as follows:—

Time.	Per-centage of gross consumption.	Time required to deliver total consumption.
		hours.
Between 6 and 7 A.M.	3·735	26·77
,, 7 ,, 8 ,,	5·209	19·19
,, 8 ,, 9 ,,	6·192	16·14
,, 9 ,, 10 ,,	6·438	15·53
,, 10 ,, 11 ,,	7·076	14·13
,, 11 ,, 12 ,,	7·764	12·88
,, 12 ,, 1 P.M.	5·995	16·68
,, 1 ,, 2 ,,	5·946	16·82
,, 2 ,, 3 ,,	6·388	15·64
,, 3 ,, 4 ,,	7·862	12·72
,, 4 ,, 5 ,,	5·209	19·19
,, 5 ,, 6 ,,	6·290	15·90
,, 6 ,, 7 ,,	3·685	27·13
,, 7 ,, 8 ,,	5·012	20·00
,, 8 ,, 9 ,,	3·047	32·81
,, 9 ,, 6 A.M.	14·152	68·26

So that the greatest consumption appears to take place between 11 and 12 A.M. and 3 and 4 P.M.

Mr. Hawksley (p. 43, vol. 2, 'First Report of Committee on State of Large Towns') states, that in order to meet this irregularity, he divides the length of the main in a street into lengths of 200 yards, and assigns to each the quantity to be delivered, supposing it to be discharged in four hours. Allowing 4 feet for the loss of head for every 200 yards, he calculates the diameter by the formula $\frac{1}{15}\sqrt[5]{q\frac{2l}{h}} = d$, in which

d = the diameter sought;
l = the length in yards;
h = the head in feet;
q = the quantity in gallons to be discharged per hour.

He also adopts, to ascertain the power required to overcome the friction, the formula $P = \frac{Q\,l}{140\,d^5}$; in which d = the diameter; P = the power; Q = the delivery; and l = the length.

The constant delivery system, it is fair to state, has many able and conscientious opponents, and doubtlessly it would in many cases be injudicious to destroy an existing system of works, if established on a large scale, for the introduction of a more perfect mode of supply. This, like so many other questions, is, after all, one of economy to a great extent, although mere monetary considerations should be allowed little weight against those affecting public health. The appreciation of the degree of importance to

be attached to either of the determining motives forms one of the most delicate branches of the professional duties of an engineer.

If, however, we state the theoretical conditions to be fulfilled by a town supply, on the supposition that nothing has hitherto been performed towards its execution, it will be easy to ascertain the modifications advisable under any given circumstances.

The purest water ought to be conducted to a small service reservoir, covered, and at a height sufficient to discharge the water at any part of the town. The house delivery ought to be effected in such a manner that water should be able to be drawn at any time and at any reasonable elevation. To prevent danger from fire it is advisable to arrange the distribution so that the water may be discharged over the roofs of the houses by means of hose screwed upon the mains in the streets. For this purpose, fire-plugs should be placed alternately on either side of the streets, at about every 100 yards apart, and as the hose is generally made 2½ inches diameter, it would be preferable not to lay down mains of less than the same dimension, in positions where fire-plugs are likely to be attached to them. In laying mains they should be kept at a greater depth in wide open streets than in narrow courts, and on the average about 4 feet from the surface. The quantity to be calculated for any given population may usually be reckoned at 20 gallons per head per day, which will include all ordinary trade consumption they may require.

The reader is referred for further information to Claudel's 'Formules à l'Usage des Ingénieurs,'—Morin's 'Aide-Mémoire de Mécanique Pratique,'—D'Aubuisson's 'Traité d'Hydraulique,'—Girard's 'Description, &c. de la Distribution des Eaux de l'Ourc,'—Génieys, 'Essai sur les Moyens de conduire, d'élever, et de distribuer les Eaux,'—Matthews' 'Hydraulia,'—The several Parliamentary Reports upon the Health of Towns and the Supply of Water,—Mr. Wicksteed's Account of the East London Water-Works, and several detached Papers on Water Supply,—Mr. Homersham's Reports,—Mr. Beardmore's Tables,—Mr. Peacocke's Researches in Hydraulics,—Neville on Hydraulics,—Downing's Practical Hydraulics,—Rules and Formulæ of the Madras Irrigation Department,—Dupuit, 'Traité de la Conduite des Eaux,'—Darcy, 'Les Fontaines publiques de Dijon.'

WATER-WHEELS.*—Water, in movement, is able to communicate power by its action upon a body offering resistance to its motion in the direction it is naturally inclined to follow; or it is able to act in a negative manner, by destroying or diminishing the velocity which any body moving in it may possess. In practical mechanics, water acts in various manners upon engines communicating in their turn movement to other descriptions of machinery immediately in contact with the raw materials to be acted upon. Our present object is the consideration of the latter class of action.

In all investigations with respect to hydraulic machinery, there are three branches to be considered; viz. 1. The force of the current producing motion, or the weight of the water P flowing per second, and H the total fall, which is represented by $P\,H$; 2. The power of the machine, or the portion of the current K, acting with a velocity v upon that portion of the machinery it strikes: this is represented by $K\,v$, and is the dynamical effect produced, whose expression is $p\,v$; p being a weight equivalent to the sum of the resistances to movement reduced to what they would be if they struck the wheel at the same point with K, but in an opposite direction; 3. The

* By G. R. Burnell, C.E.

useful power of the machine, or $p' v$; p' being p minus the sum of the passive resistances to be overcome.

These forces are usually expressed in units of work whose measure consists in a certain weight lifted to a certain height in a definite period. As the useful effect of horse-power is most generally known, it has been adopted as the measure; and by almost universal consent it is assumed to be such that one horse can raise 33,000 lbs. one foot in height per minute. The term 'one horse-power' must, therefore, be considered to be the expression of such an effort.

Hydraulic machinery may be of two descriptions: the first consisting of such engines as possess a movement of rotation; the second, of such as have an alternative movement. Water-wheels, including turbines and reaction wheels of all kinds, are comprised in the first; the water-pressure-engines, and the hydraulic ram, are included in the second: these last have been already alluded to in the article upon 'Water Meadows.'

Water-wheels are subdivided into those with floats or blades, and those with buckets. The first are again subdivided into classes, some of which have the floats straight, others curved; or which move in breasts, races, or water-troughs, either rectilinear or curved. In the second class are comprised the bucket-wheels receiving water upon the summit, or at a lower point. In addition to these are the horizontal wheels, which are either set in motion by an isolated vein, or placed in a cylinder, or, as in the case of the turbines, they are placed externally to a cylinder conducting the water. The several descriptions of water-wheels may be briefly stated as follows:

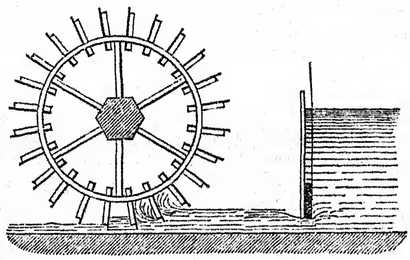
1. Vertical Wheels with floats straight, and working in a straight mill-race.
2. ,, ,, in close circular race.
3. ,, ,, in unlimited water.
4. ,, ,, curved, called Poncelet's wheels.
5. ,, overshot, with buckets.
6. Horizontal Wheels, struck by an isolated vein.
7. ,, working in a cylinder.
8. ,, Fourneyron's turbines.
9. ,, with partitions.
10. ,, reaction wheels.

And in addition, we may perhaps place in a separate class the two descriptions of breast wheels known as the high and the low breast wheel, receiving the motive power at points intermediate between the summit and the horizontal line passing through the axle; also of late, a description of wheel called the *back-shot*, in which the water is carried beyond the summit, and returns to strike the wheel a little below that point on the descending side.

The parts of water-wheels and machinery which may require to be defined are as follows. The *fore bay* is the channel leading the water upon the wheel; it generally has a hatch or sluice, by which the weight of the water is regulated; the *race* is the part of the channel immediately under the working part of the wheel; the *tail bay* is that part by which the water escapes after it has exercised its effect. The wheel consists of a *shaft*, upon which are fastened the *arms*, bearing in their turn the *periphery* of the wheel. Sometimes this is close boarded or *soled*, at others it is left open at intervals to allow of the ventilation of the buckets. The sides of the buckets which serve to keep the water upon the wheel are called the *shrouds*. Motion is communicated to the working parts of the machinery by gearing on the segments of the wheel, or by first-motion or bevelled wheels, called *pit wheels*, upon the axle itself.

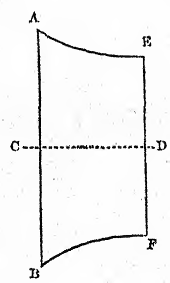
1. *Vertical Wheels with straight Floats working in a straight Mill-Race.*

This description of wheel was formerly the most frequently employed, but at present it is only used when the fall is insignificant and does not exceed 5 feet. The water is brought under the wheel from the fore bay by a trough, whose sides almost touch the floats, and leave merely a sufficient interval to allow of the movement of the wheel. Upon the trough a hatch is fixed to regulate the quantity of water to be admitted.



In leaving the hatch the fluid vein becomes contracted, it then extends and reaches the sides of the race. If therefore, at the section of the greatest contraction it should possess the velocity due the head of water in the fore bay, a considerable portion will be lost; firstly, on account of the dilatation, and secondly, on account of the friction in the race, before it can reach the floats. If the race be long, this loss may be such that the water will only retain $\frac{2}{3}$ths of its initial velocity when it reaches the floats.

In undershot wheels of the description we are considering at present, the water acts entirely by its shock, and it is therefore necessary that V, or the velocity of the current, should be as great as possible. Its diminution, and the consequent loss of power, may be prevented by placing the hatch as near the wheel as it can conveniently be placed, and by forming the channel so as to reduce the contraction to a minimum. The sides and bottom above the opening are, for this purpose, to be made in continuation with those of the mill-race, and its head in the fore bay is to be opened out as in the accompanying sketch, representing the horizontal section. Poncelet recommends also that the hatches should be inclined; for he found that with an inclination of 63° to the horizon, the coefficient of contraction was 0·75, with an inclination of 45° it was 0·80, whilst a vertical hatch under similar circumstances gave a coefficient of 0·70.



Immediately beyond the hatch the race passes under the wheel with a slight inclination, and it thence flows on in a straight line. The width is determined by the quantity of water to be discharged; the depth of the water, supposing the wheel to be removed, should never exceed 10 inches or fall short of 6 inches. When it is less than the latter dimension, the quantity of water escaping between the floor of the race and the outer edge of the wheel becomes proportionally too great, and the force of the current becomes considerably diminished. To reduce this loss to a minimum, it is advisable to leave only a space of about $\frac{1}{2}$ or $\frac{3}{4}$ of an inch between the wheel and the race-floor.

The most carefully constructed undershot wheels at the present day, however, are no longer constructed with perfectly straight races. An inclination is given from the hatch to the level of the lower edge of the second float on the upside of the vertical diameter, of about $\frac{1}{12}$th or $\frac{1}{15}$th; the bottom then curves concentrically to the wheel until it arrives at the vertical line passing through its centre; it then falls suddenly about 4 inches at least, and afterwards runs away with as great an inclination as the locality will admit. The width, immediately before striking the floats, is somewhat

smaller than that of the latter; it augments gradually, and at the vertical diameter is wide enough to enclose it: in this manner the water strikes the wheel with its whole mass without any loss by the way, and the lowering of the bottom facilitates the escape of the water after it has exercised all its effect.

It has been seen above that the width of the floats is fixed by the width of the race: their height or dimension measured upon any radius of the wheel must be such that the heaping up of the water against the first float it strikes should take place under such conditions as not to lose any of the power. This is effected by making the floats about three times the height of the water in the race, provided they do not exceed from 2 feet to 2 feet 2 inches. The distance from one float to another measured on the exterior circumference of the wheel should be a little less than their height. Their number will then depend upon the diameter of the wheel, and this may be considered to be arbitrary.

In fact, the dynamical effect of the wheel is only in proportion to the velocity of the floats; it has a necessary connection with the latter alone, and is independent of the diameter. When therefore it is required to fix the diameter, it is determined by the number of revolutions it may be deemed advisable to make the wheel perform in a certain time, in order to transmit the power to the machinery, producing the useful action with the greatest simplicity, and the intervention of the smallest number of intermediate motions. It is also desirable that the wheel should act as a fly-wheel so as to insure an equable movement. Take u the velocity of the extremity of the floats, N the number of revolutions required in a minute, the diameter will be $\frac{60u}{\pi N}$, or $19\cdot1\frac{u}{N}$. In the most favourable conditions $u = 1\cdot7\sqrt{H}$ (H = the total fall), consequently the diameter will be $\frac{32}{N}\sqrt{H}$. Practically, however, it varies from about 13 to 26 feet.

According to the diameter adopted, the wheel will have the number of floats indicated in the Table annexed. The numbers are all multiples of four, because millwrights are accustomed to place a definite number of floats in each of the quadrants of a wheel. There would be no inconvenience in augmenting any of the numbers given in the Table by four.

Diameter.		Floats.
ft.	in.	
13	4	28
16	6	32
19	8	36
22	10	40
26	3	44

According to Bélanger, there would appear to be a theoretical advantage in making the blades, whatever be their velocity, dip so that the extent to which they are covered by the water should be equal to the depth of the fluid vein, or even a little in excess of that depth if the velocity be very great. It has been found practically that this advantage does exist when the floats are immersed to ⅔rds or ¾ths of the thickness of the fluid vein; and it has also been ascertained that there is no loss when the blades are immersed to a depth equal to the whole thickness. It follows from this that the bottom of the race should be kept below the level of the water at the back of the wheel.

Some engineers, Déparcieux amongst others, believed that by inclining the floats at an angle of from 20° to 22° to the radii, in the direction of the incoming water, the useful effect of the wheels would be increased. But it would appear from Bossut's experiments, that so far is this from being the case with undershot wheels, that floats inclined at angles of 0°, 8°, 12°, and 16°, gave results which were respectively as 1; 0·998; 0·956; and 0·949. No experiments are upon record where the precise inclination recommended by Déparcieux was tried; but from those recorded by Bossut, it

would seem that the inclination of the floats, so far from being advantageous, was positively prejudicial.

In a perfectly straight race in which the wheel might dip in the water in the tail bay, a condition which does not exist in the most modern mills, it is true that the inclination of the floats would be advantageous, insomuch that they would not be likely to lift and carry with them a certain quantity of water, which would act in the opposite direction to the movement of the wheel, and thus diminish its effect. This inconvenience may also be obviated by the adoption of a system frequently employed in wheels erected upon small branches of rivers, or in positions where the fall is but trifling ; it consists in forming the floats of separate parts inclined a little to the radius, but always at a greater angle in proportion as they approach the extremity of the wheel, somewhat in a cycloidal form.

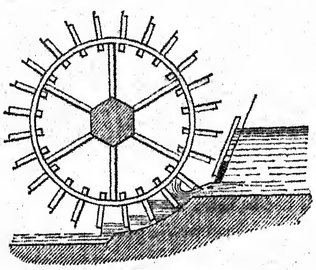
Rims have been added to the floats by some engineers, for the purpose of increasing the dynamical effect. But it has been observed that their action is insignificant so long as the floats receiving the shock are confined within a race, for the race itself produces precisely the effect desired. The increased effect in other cases is much more likely to be obtained by enclosing the floats within circular plates or shrouds. In narrow wheels, cast-iron floats slightly cylindrical, the axis of the cylinder being in the direction of the radii, produce the same effects as the rims.

It is found theoretically, that a current of water acting by its shock upon a wheel with floats is only able to produce a useful action equal to half of the greatest effect it is capable of producing ; or, calling the weight of the water supplied per second P, and the total fall H, the theoretical effect would be $\frac{1}{2}$ P H. This result is far from being obtained in practice, for Smeaton's experiments appear to shew, that instead of being $\frac{1}{2}$ P H, it is $\frac{1}{6}$ P H, or at the maximum $\frac{1}{4}$ P H.

The useful effect of this description of wheel is very small ; but as it is independent of the diameter, and this may be made to vary within the range of from 7 to 28 feet, without occasioning any loss of power, and as the velocity may be altered within a considerable range, these wheels are advantageous when great direct velocity of rotation is required, or the velocity of the wheel may be exposed to variations.

2. *Vertical Float Wheels working in a close Breast.*

It has been shewn that the useful effect of an undershot wheel is increased by making the breast concentric to its exterior circumference. The advantage thus gained is proportionate to the arc of the wheel so enclosed ; at the present day, therefore, the latter is made as large as the disposable fall will allow, and is usually from $\frac{2}{3}$rds to $\frac{3}{4}$ths of its total height. The circular part of the breast requires to be executed with great care, so that its surface should offer the least resistance possible on account of the friction, and its axis must be exactly the same with that of the wheel.



A space of about $\frac{1}{2}$ an inch is left between the circumference of the wheel and the surface of the breast, to allow a little play to the floats. The width of the breast is made so as to allow the stream of water to flow with a depth varying between the maximum of 8 and the minimum of 6 inches. The diameter of the wheel and the number of floats will be ascertained by the rules given in the last section ; the height of the floats should be three times the depth of the water upon the breast. They are sometimes inclined to the direction of the radius.

It is important that the sluice be placed so that the water may strike the first float in a direction nearly perpendicular to its face; it would even be preferable if it could be made to fall over the sluice immediately above the curved portion of the breast.

The causes of loss of power from the real dynamical effort exercised upon these wheels are, firstly, the water rarely strikes the blades perpendicularly; secondly, a portion escapes between the wheel and the breast without exercising any influence; thirdly, the portion of the wheel immersed in the water loses a weight corresponding with the quantity of water it displaces. From these combined causes the useful effect of undershot wheels of the description we are considering has never been observed to exceed 0·772 P H; usually it is considered to be about from 0·60 P H to 0·65 P H.

3. *Vertical Float Wheels in unlimited Water, or Wheels working upon Boats on Rivers.*

This description of wheel is principally employed upon boats moored in the current of large rivers on the Continent, and it has occasionally been employed to communicate motion to a series of stampers acting upon the rocks in the middle of the rapids of the American rivers. It is evident that it can only be applied in water-courses where it would be impossible to establish any navigation, or in the smaller or more unserviceable branches of large streams. In almost all cases the natural velocity of the stream alone acts upon the wheel, without being in any way confined or directed by a race or channel of any description: it is to such wheels that these observations are confined.

The diameter of these wheels rarely exceeds from 13 to 17 feet; the blades or floats are usually 12 in number, but it is sometimes considered to be more advantageous to increase the number to 18 or to 24. Fabre, who paid particular attention to this description of wheels, states that the height of the floats should not exceed 0·28 of the radius of the wheel, measured to the centre of percussion, so that it would only be about 0·25 of the entire radius; very frequently it is made only 0·20 of the radius. He made the whole of his floats immerge, a system which would answer in deep rivers, where, from some peculiar circumstances, the greatest velocity of the current might be below the surface. Otherwise, and in the greater number of instances, the effect of these wheels is the greatest when a portion of the floats (in the vertical position of the wheel) rises above the floating line. The width of the wheels varies from 8 feet to 17 feet 6 inches.

Déparcieux made some experiments, subsequently confirmed to a considerable extent by Bossut, which warrant the assertion that when the floats were inclined at an angle of 30° to the radius touching their inner edge, their action was augmented. D'Aubuisson expresses the opinion, that if the floats were formed as for some undershot wheels, of separate parts, inclined a little to the radius, but always at a greater angle in proportion as they approach the extremity of the wheel, and if they were close shrouded, their effective action would be increased. Navier recommends that the floats should be inclined at an angle of 30° when the wheel dips from $\frac{1}{4}$th to $\frac{1}{5}$th of its radius; and at an angle of 15° when it dips $\frac{1}{3}$rd, the maximum of immersion. In all cases the inclination to be towards the up-side of the stream.

On some rivers, such as the Rhone, the wheels dip as much as 1 foot 8 inches below the surface; but it is usual in practice only to make them descend about 1 foot 2 inches below that line.

The theoretical effect of these mills is ascertained by the formula $Pw = 20\ S\ V^2$, in which

Pw = the effective power which the working shaft is able to transmit;

S = the sectional area of the part of the float situated upon the vertical radius of the wheel, measured in the direction of that radius;

V = the velocity of the current at the point where the wheel is situated; it may be considered to be the mean velocity of the water striking the floats.

4. *Vertical Undershot Float Wheels, working with curved Floats, Poncelet's Wheels.*

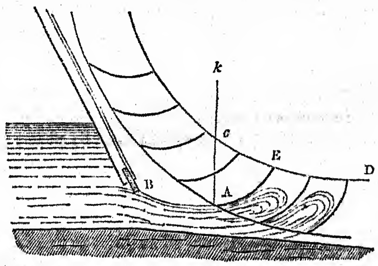
Although undershot wheels with straight floats do not yield more than a fourth or a fifth of the motive power acting upon them, they possess certain advantages which induce engineers to adopt them in many cases: their construction, when properly performed, is economical, and they can receive a considerable velocity without any appreciable loss of power. M. Poncelet has succeeded in retaining these advantages, and simultaneously in avoiding much of the diminution of effect, by substituting curved floats for the ordinary straight ones.

From a series of experiments performed by that eminent philosopher, it would appear that the speed of a wheel provided with curved floats yielding the greatest effect should be about 0·55 of the velocity of the current; it may vary from 0·50 to 0·60 without any appreciable difference. The dynamical effect is not less than 0·75 P h for small falls with great openings of the sluices, or than 0·65 for great falls with small openings; h in this case representing the head of water producing the velocity. Compared with the motive power P H, the dynamical effect will be 0·60, and may under some circumstances descend to 0·50 of P H. We have seen that with straight floats these numerical coefficients do not exceed 0·32 and 0·25 respectively, so that the curvature of the floats doubles the effective powers of the wheel.

M. Poncelet gives a series of rules for the construction of these wheels, from which the following remarks with respect to the formation of the characteristic part, the curved floats, are extracted.

The number of floats should be double that already indicated for undershot wheels with straight floats.

Their height in the direction of the radius, or the distance from the exterior to the interior circumference of the wheel, should be at least $\frac{1}{4}$th of the effective fall; it is made $\frac{1}{3}$rd when the fall is about 5 feet effective, and $\frac{1}{2}$ when it is even less.

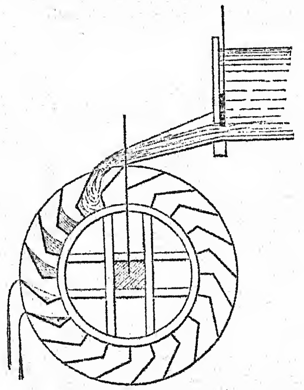


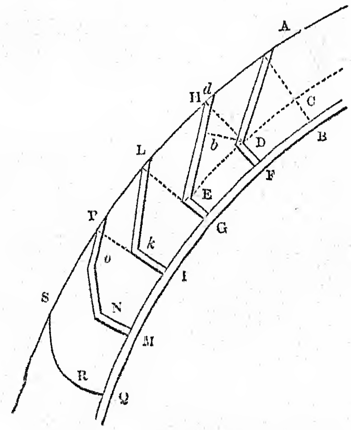
The lower element of the curvature of the floats, which forms an angle infinitesimally small with the external circumference when the stream communicating motion is very shallow, will form one of 24° or 30° when it increases in depth, and will, in fact, augment in proportion to the depth of the stream. The curvature of the blades is ascertained by the following simple construction. From the point A, where the stream A B meets the exterior circumference, raise the perpendicular A k, and from the point c, where it strikes the inner circumference with the radius c A, describe the arc A E, which will give the form of the floats. They may be executed either of small boards, set like the staves of a cask, or of wrought iron.

A little beyond the vertical diameter of the wheel, the floor of the race is lowered abruptly, so that the water shall not meet with any obstacle to its escaping from the floats.

5. *Vertical Overshot Wheels, with Buckets.*

In these wheels the water is carried over the top of the vertical diameter, and escapes in such a manner as to strike the buckets upon the side towards the lower part of the stream. It acts, therefore, slightly by its shock, but principally by its dead weight. Such wheels consist of a horizontal axle,—of the arms with their struts,—of the rim with its sole, shrouds, and buckets.





The axle may be either of wood or of iron. If of wood, it should be of oak, or of a wood at least of a degree of hardness equal thereto. Its length will depend, of course, upon the diameter of the wheel, and its dimension is made to vary from 1 foot 8 inches to 3 feet 4 inches square. Timber of such dimensions is becoming more and more rare, and cast iron is now almost universally substituted for it, excepting under peculiar local circumstances. The arms, when the wheel is constructed of wood, are not framed into the axle, but they are put together in pairs, and the two pairs meeting in the centre leave a square space adapted to receive the axle upon which they are fixed by means of keys and wedges; the intermediate parts of the rim are supported by braces when the wheel is exposed to sudden shocks or is of considerable dimensions. In modern wheels, even of wood, the arms are made to fit into a cast-iron nave keyed upon the axle, and they are then arranged like the spokes of a wheel.

In wooden wheels the rim usually serves to act as shrouds to the buckets, and is made in the best wheels from 10 to 12 inches in width. Even for those intended to receive a large volume of water, the depth thus afforded for the buckets need not exceed 12 inches; for it is preferable to increase the width of the wheel rather than to augment the depth. The sole of the buckets is formed by nailing planks to the under-side of the shrouds, and a provision is commonly made to insure the ventilation of the buckets by a series of holes bored into the sole in the upper part.

The buckets are formed in various manners, the simplest of which is the following: An arc of the circle described by the radius of the exterior circumference A S, and a similar arc, B S, described by the radius of the inner circumference, are drawn, which give the depth of the bucket plus the thickness of the sole. Through C, a point upon A B, $\frac{1}{3}$rd of the distance between A and B, a third circle C D E is drawn; as the centre of gravity of the water contained in the buckets is habitually upon it, or very near to it, the radius of this circle is called the dynamic radius of the wheel. The distance

between the buckets measured upon this circle is usually about 13 inches; but as millwrights divide the wheel into quarters, and place a definite number of buckets in each quarter, the above distance may vary according to the size of the wheel. The number of buckets consequently will not be proportional to the diameters, but it will be as indicated by the accompanying Table. The diameter indicated by the first column is that of the exterior circumference; it is, correctly speaking, the real diameter of the wheel, and is to be understood as being meant when the sign D is used in the following description.

Diameter.		Buckets.
ft.	in.	
10	0	24
13	4	36
16	6	44
19	8	56
26	3	76
32	10	96
39	6	108

When the circumference of the dynamic radius shall have been divided into the number of spaces corresponding with the intended number of the buckets, lines are drawn from the points C, D, E, &c. to the centre, and they will settle the position of the smaller part of the bucket. The larger part is fixed upon the principle, that firstly, the angle H E G, formed by the two parts, should be as small as possible, in order to retain the water for a longer period; but at the same time it is necessary to observe that it must be sufficiently large to leave a space D *b* able to receive all the water without difficulty, and in such a manner as not to cause any of it to rebound after having struck the wheel. It is therefore necessary that D *b* should be deeper than the thickness of the fluid vein; by widening the hatch and the buckets, it is true that the latter thickness may be made of any dimension; but it is found that D *b* ought not to be less than from 4½ to 5 inches. The angle H E G will then vary from 110° to 118°, according to the diameter of the wheel, when it ranges between 13 feet 4 inches to 39 feet 6 inches; so that the inclination of the wider part of the bucket will form an angle of about 31° to the tangent at its point of contact with the outer circumference: it should never exceed 33°. In practice it will be found sufficient to make the outer edge of the succeeding bucket terminate at the prolongation of the radius passing on the inner side of the smaller bucket preceding it.

In some cases the bucket is divided upon a line equidistant from L and I, or I K $= \frac{1}{2}$ L P; L being ascertained by the prolongation of the outer face of the first portion of the preceding bucket G E H. Occasionally the planks of which the buckets are formed are placed as in P O N M, but the repairs of such wheels are more difficult and expensive than where a simpler form is used. When, however, the buckets are made of wrought iron, the form indicated by R S is unquestionably the most advantageous, as it retains the water to the lowest point of the revolution of the wheel.

The water is carried over the top of the wheel at a trifling distance from it, and made to strike the second or third bucket beyond the summit, at a distance of about 1 foot 8 inches to 2 feet beyond the vertical line passing through its centre. The stream at the point where it leaves the channel should be somewhat narrower than the wheel, and be so directed that it impinge upon the bucket as directly and perpendicularly as possible.

The length of the buckets, or the distance between the shrouds, measured upon the face of the wheel, will be determined by the volume of water it ought to deliver. If we take Q to represent the volume delivered by the channel in 1″, d the distance from one bucket to the other upon the external circumference, and v the velocity of any point in that circumference, it is evident that a number of buckets equal to $\frac{v}{d}$

will pass before the hatch in a second, and that consequently each of them would take a quantity of water $= \frac{Q\,d}{v}$. It is necessary that the bucket should not only be able to contain this quantity, but also it is found advisable to make it of three times the capacity necessary to do so, or the water would have a tendency to escape too rapidly. If $l =$ the length of the bucket, and $S =$ the sectional area of the fluid mass it can contain at the moment of its passing before the sluice, $S\,l$ will be its capacity, and it is necessary that $S\,l = 3\frac{Q\,d}{v} = 180\frac{Q}{M\,N}$; M being the number of buckets on the wheel, and N the number of revolutions it makes in a minute, since $d = \frac{\pi\,D}{M}$, and $v = \frac{\pi\,D\,N}{60}$. Thus $l = 180\frac{Q}{M\,N\,S}$, which must be its dimensions in the clear.

The theoretical effect of a stream delivering a quantity of water P in 1″ falling from a height $H = P\,H$; but there are several causes which in reality diminish this value. A certain quantity of the power is lost between the discharge of the water from the sluice and its striking the wheel; and another portion is lost by reason of the obliquity of its action upon the first bucket it strikes. It is therefore important to keep the bottom of the reservoir as close as possible to the top of the wheel.

A second cause of loss of power arises from the form of the buckets, which allow the water to escape before it reaches the level of the tail bay. Great attention then should be paid to their construction, to insure their retaining the water to the lowest possible point of their revolution.

The centrifugal force of the water upon the loaded side of the wheel will give rise to a loss of power varying with the velocity at which it revolves. For a wheel of about 14 feet diameter, with a velocity of about 9 feet 9 inches at the periphery, this cause of loss is not important, but in small overshot wheels, such as are found in mining districts, with a diameter of 8 feet, and a velocity at the periphery of 15 feet per second, it is sufficiently great to require serious attention.

We may therefore resume the rules affecting the working conditions of an overshot wheel, as follows. 1. The loss of power will be reduced in proportion to the correct disposition of the sluice or the channel. 2. It will be smallest when the diameter of the wheel is as nearly as possible equal to the height of the fall. 3. When the diameter thus approaches to the height of the fall, the loss of power will be the smallest in such cases as admit of the wheels revolving at half the velocity of the fluid striking the buckets. 4. The effective power of the wheel will be regulated by the length of time the buckets are able to retain the water.

A well-constructed overshot wheel working with small velocity will yield sometimes as much as 0·80 P H, but under the usual conditions of construction, and with a velocity of from 3 feet 6 inches to 7 feet per second, and the buckets only half-filled, the usual effect is comprised within 0·70 and 0·75 P H. If the velocity exceed that stated above, as is frequently the case with wheels driving the shingling, or puddling, hammers of iron-works, which have buckets usually designed to be filled to ⅔rds of their capacity, the effect will often not exceed 0·60 P H, or even occasionally 0·37 P H. This is to be accounted for by the fact that the water striking the buckets with great force rebounds without producing much effect. In such cases it is particularly advisable to enclose the wheel.

A. *Breast-Wheels.*

In overshot wheels, as already seen, the water is carried over the summit and poured into the second or third bucket beyond the vertical line passing through the

centre. The lower part of the wheel then must revolve in a direction opposite to that of the stream in the tail bay, so that if by any accident the back water is penned up, the wheel may be exposed to a retarding force, sometimes of considerable importance. In order to avoid this loss of power the water is poured upon the back of the wheel; its lower portion then revolving in the same direction as the current of the tail bay, it may be immersed to a depth of about 1 foot without its being seriously retarded. The wheel may under such circumstances be lowered to the extent named, and the effective height of the fall proportionally increased.

Wheels receiving the water on the back of the wheels are called high, or low, breast-wheels, according to whether they receive the water above or below the horizontal line passing through the centre. In addition to the advantage before cited, they possess another, viz. that inasmuch as they receive the water below their summit, the latter may be, and usually is, kept above the level of the water in the reservoir. Under certain circumstances this advantage becomes very important, because a larger wheel retains more effectually the power communicated to it than a smaller one would do.

The water is usually brought upon breast-wheels, by a trough, at the end of which is a vane to regulate its admission to a series of guides serving to direct the water into the buckets. These guides are usually made vertical, and the buckets are disposed in such a manner as to continue that direction when they pass in front of the openings.

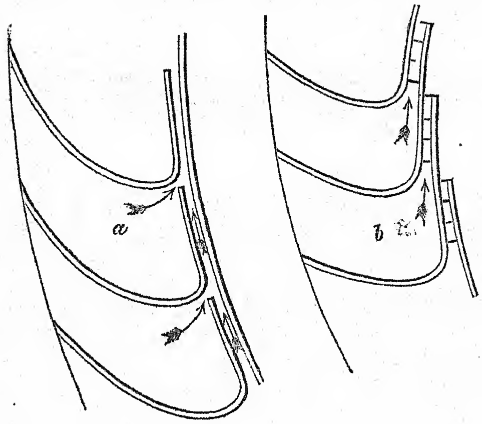
The loss of head arising from the form of the buckets, and the centrifugal force being proportional to the diameter, there will naturally be an advantage in making the latter nearly equal to the fall. It follows, that inasmuch as in breast-wheels the summit must not be below the level of the water in the reservoir, the dynamical effect will be the greatest when the water strikes the wheel at the smallest distance from the summit of the wheel. In the greater number of high breast-wheels this distance, measured on the exterior circumference, may be 30°, or even less, for wheels of 20 feet and upwards; in small wheels it is usually considered advisable to make it 40°. Many millwrights even make the water strike the wheel at an angle of about 52°, but evidently the water in such a case has no sooner entered the buckets than it is poured out again. The loaded arc of the wheel becomes proportionally so small that it would be far more advantageous to adopt a wheel of less diameter. Should the fall in fact not exceed 8 feet, it will be found most advantageous to adopt an undershot wheel working in a closed channel, which will carry the motive power of the water to the lowest point of the revolution.

From the observations made by M. Morin, it would appear that under the most favourable conditions the dynamical effect of breast-wheels hardly exceeds 0·788 P H. Generally speaking, it would not exceed 0·75 P H, and M. D'Aubuisson is of opinion that it should not be calculated to be in practice above 0·70 P H.

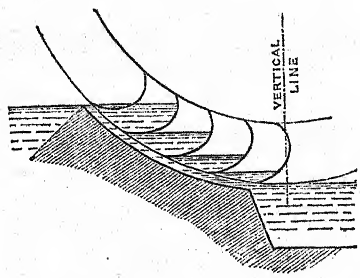
B. The *back-shot* wheel may be considered a species of *overshot*, for it consists of a channel carrying the water over the top, and provided with a sluice so disposed as to cause it to revert and strike the wheel at the back. This arrangement involves a trifling loss of fall between the channel and the wheel; but on the other hand it obviates the inconvenience alluded to as arising from the flooding of the tail bay, by causing the wheel to revolve in the direction of the current in the latter.

Mr. W. Fairbairn has done more to improve the effective power of bucketed water-wheels than any other constructor of late years, by the introduction of what he calls ventilated buckets. As he observed in the Paper upon this subject presented to the Institution of Civil Engineers, "close bucketed wheels labour under great difficulties when receiving the water through the same orifice at which the air escapes, and in

some wheels the forms and construction of the buckets are such as almost entirely to prevent the entrance of the water." The modifications he introduced may generally be stated to have been for the purpose of preventing the condensation of the air, and for permitting its escape during the filling of the bucket with water, as also its re-admission during the discharge of the water into the lower mill-race.



The sketches in the margin illustrate the mode of ventilation proposed by Mr. Fairbairn for (*a*) high or (*b*) low breast-wheels, the former being usually close soled. It is also to be observed, that Mr. Fairbairn attaches great importance to the construction of the breast. He makes it fall away suddenly at a short distance on the near side of the line passing through the centre, in order to secure the rapid clearance of the buckets directly they shall arrive at that point of the revolution.



6. *Horizontal Wheels, struck by an isolated Vein of Water.*

In the South of France a great number of mills exist, in which the wheel, instead of occupying a vertical position as it usually does in Northern Europe, is placed horizontally. From the fact that this position dispenses with all complication of movement in the transmission of the power, it is preferred in countries where skilled labour is expensive, and the execution of repairs difficult. In such mills the same shaft which carries the wheel-communicating power at the bottom carries the mill-stones above; it works upon a pivot let into a moveable seating able to be raised or lowered, to secure the proper intervals between the fixed or revolving stones.

The old mills figured in Belidor's 'Architecture Hydraulique' consist of a vertical shaft, upon which are fixed a series of blades, mostly curvilinear, although of different forms in almost every instance. The water communicating motion is admitted to some of these wheels in an isolated vein by means of a pipe, in others they are placed in a cylinder open below, and the movement is produced by the escape of the water. At the latter end of the last century many rotary machines were proposed, in which the water communicated motion by reaction, and the mathematicians of that time paid considerable attention to the investigation of the laws affecting them. Still more recently, or about 1825, M. Burdin introduced the class of horizontal wheels called 'turbines' to public notice, and his pupil M. Fourneyron, together with Messrs. Zuppinger and Whitelaw, have considerably improved it.

In the horizontal mills used in the Alps and the Pyrenees the wheels are usually about 5 feet 6 inches in diameter, and only 8 inches deep; the blades are about 18 in

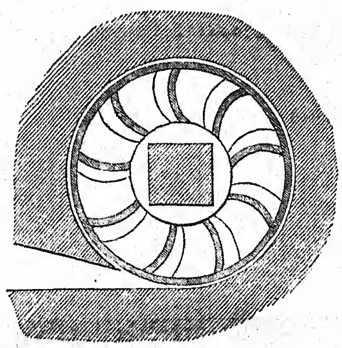
number. The portion receiving the shock is concave and of an inclined curvilinear form, so arranged that its intersections by a series of planes vertical, and perpendicular to the radius, form curves increasing as they recede from the centre. The upper element of these curves is vertical, the lower one is the more inclined in proportion as the extremity is approached, where the curvature is nearly equal to a quadrant of a circle.

The water is directed upon these wheels with a head of from 24 to 30 feet, or even more, and exercises its effect principally by its shock, if not entirely. If the floats then were normal to the direction of the current upon their whole surface, the expression of the maximum of effect, E, would be nearly $E = \frac{1}{2} Ph'$, calling h' the height really corresponding to the velocity with which the water strikes the wheel. In practice the real effect is below that given, for not only is a portion of the water wasted without striking the wheel at any point, but also the greater portion will not strike it vertically to the surface of its blades. Experiments upon the useful effect of these mills have reduced the expression given above to $\frac{1}{3}$ P H, but it is not usually considered safe to adopt a higher proportion than 0·30 P H.

7. *Horizontal Wheels working in a Cylinder.*

The last-cited description of horizontal wheels are principally employed when the stream is small in volume and the fall great; but when these conditions are reversed, the wheel is made to work in a cylinder of wood or of stone, open above and below. These wheels are, and have long been, very common on the banks of the Garonne, the Tarne, the Aveyron, and the Lot, in the South of France.

The wheels are usually made about 3 feet 4 inches diameter, and 10 inches deep; the blades are nine in number, and formed as described for wheels moving by the percussion of an isolated vein. The cylinder is made about 7 feet 6 inches deep, and 3 feet $4\frac{3}{4}$ inches diameter; the wheel being placed quite at the bottom. A channel serving to conduct the water is formed in the whole vertical height of the cylinder above the top of the wheel, it diminishes gradually to its point of discharge, where it is not more than 11 inches wide, and one of its faces is tangential to the inner curve of the cylinder. The water, after leaving the sluice at the entrance of the channel, is directed with violence against the part of the cylinder immediately opposite to it; following the new direction it thence receives, it runs round the sides of the cylinder, acquires a circular motion, descends, and strikes the wheel upon which it acts by its impulsion and its weight, communicating to it the motion thus acquired.



The space left between the wheel and the sides of the cylinder is a cause of considerable loss of power, because the centrifugal force of the descending current causes the water to adhere closely to the sides, and a great portion thus escapes without producing any effect. In the most modern machines of this description, the cylinder is made rather smaller than the wheel, which is placed immediately beneath it, so that nearly all the motive current falls upon the wheel; but even in this case there is a loss of velocity in the current, owing to the change of direction.

Morin gives a rule to calculate the number of revolutions a wheel of this description should perform in a second. It is as follows :—

$$n = 2{\cdot}1\,\frac{D'^2}{D^2}\sqrt[4]{E}, \text{ in which}$$

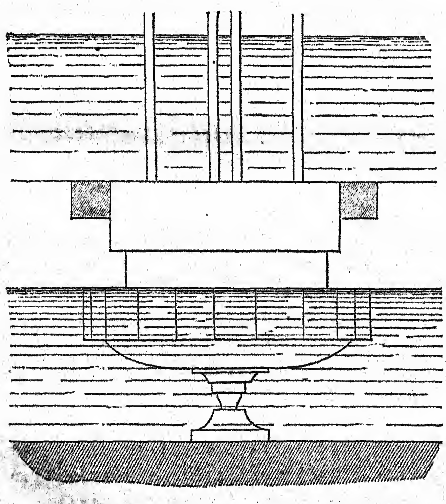
n = the number of revolutions;
D = the diameter of the cylinder in yards and decimals of yards;
D′ = the diameter of the wheel, in ditto;
E = the opening of the sluice.

The form of the curved blades is to be ascertained by the rules usually applied to the other kinds of wheels constructed with floats of that nature, observing that, to insure that the water shall exercise all its dynamical effect, it must enter and act upon the wheel without shock, and leave it without velocity. From the difficulty attending the attainment of these conditions, it arises that, perfect as these horizontal wheels are in theory, their real effect is rarely more than $\frac{1}{6}$ P H; and it is only in the most perfectly constructed modern ones that it rises to 0·25 P H. Morin, however, states that in some instances it has attained 0·35 P H; and he adds, that the maximum of effect is obtained when the velocity of the mean sheet of water, v, at the point where it strikes the wheel, is 0·45 of V, the velocity at which it flows into the cylinder.

Small as is the practical result attained, compared with the volume of water employed, the simplicity and solidity of the mechanism of these wheels may frequently render their adoption desirable. They possess another advantage, viz., they are able to work when they are flooded to a considerable height,—in fact, so long as an appreciable difference exists between the fore and the tail bays. D'Aubuisson states, that in some rivers where the fall is small, not exceeding in many cases from 4 to 5 feet, these wheels are placed from 1 foot 8 inches to 2 feet 4 inches below the surface of the ordinary waters in the river in the tail bay.

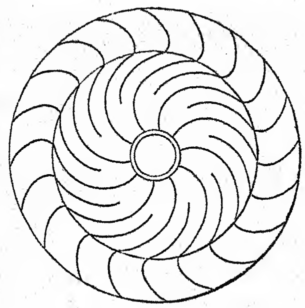
8. *Turbines of M. Fourneyron.*

The great waste of water which takes place in all horizontal wheels struck by an isolated vein, or working in a cylinder, led to numerous modifications whose success did not promise much useful result, until M. Fourneyron, continuing the investigations of M. Burdin, was led to discover the principles upon which turbines, or whirl-wheels, are constructed. Instead of placing the wheel *within*, he places it *outside* the cylinder, round which it works like a ring, with only sufficient play to insure the action of the machinery. The cylinder is made with a series of orifices upon its circumference, and the water is directed against the curved blades of the annular wheel by a series of directing partitions, striking them all at the same time. When these machines are carefully made, they are found to be equally fitted



for large or small falls; they weigh very little in comparison with the effect produced, and are able to work as well when under great depths of water as in their normal conditions.

Since these wheels perform as well under great as under small heads of water in the tail bay, the first rule to be observed in their construction is to place them below the level of the lowest water, which will render the total fall available at all times. They consist, like all other horizontal wheels, of three parts; the cylinder with its supports,—the turbine itself, properly so called, or the annular wheel,—and the sluice. The cylinder is usually made of cast iron, and has in the centre a water-tight passage for the vertical first-motion shaft: the partitions directing the water to the blades of the turbine are of wrought iron. The turbine consists of two horizontal cast-iron plates, maintained at their respective distances by the blades of wrought iron; the lower plate is cast with a seating to receive the vertical shaft, which is keyed on to it, and works in a cup or socket able to be raised as required. The blades are of a simple curve, the first element of which is perpendicular to the inner circumference of the turbine, and the last forms an angle of 15° with the outer circumference. The directing plates of the cylinder are made deeper than the blades of the turbine, and, for about 10 inches of their length, are in a straight line forming an angle of 30° with the exterior surface: the form of the remaining portion is not of importance. Inside the cylinder works the sluice, formed by a second cylinder working vertically, and opening the passages left in the side of the larger one. Its motion is regulated by a rack and pinion: care must be taken to round the lower edge of the sluice so as not to interfere with the discharge of the water.



It is to be observed, that as the blades of turbines are composed of a series of vertical elements, the water in leaving them is only affected by the centrifugal force which produces the rotary movement. Neither the weight nor the shock of the stream is employed; and this may be said to be the only machine in which motion is obtained by the centrifugal force.

M. Fourneyron has published the rules to be observed in the construction of turbines; but by his patent he has reserved to himself the right of constructing them so long as the patent may last. The rules are briefly as follows:

The volume of water will be determined by the total fall, and as it is known that a turbine will yield an effective power equal to 0·70 of that applied to the machine, the quantity to be supplied per second will be $Q = \frac{P\,v}{700\ H}$. The numeration of these formulæ is of course based upon the metrical system of weights and measures; but if we adopt the yard and its decimal subdivisions throughout, little practical error will arise.

For moderate falls, the velocity of the water in the cylindrical reservoir should not exceed $\frac{1}{4}$th or $\frac{1}{5}$th of that due to the total fall; the mean velocity of the water, or U, will then be taken at $\frac{1}{4}$th or $\frac{1}{5}$th of the velocity due to H, and the diameter will be calculated by the formula $D = \sqrt{\frac{Q}{0{\cdot}7854\ U}}$. The interior diameter of the wheel is made about $1\frac{3}{4}''$ or $2''$ greater than that of the cylinder, and is again from 0·70 to 0·80 of its own outer diameter.

It is found that the useful effect of turbines is greater in the same proportion that the opening of the sluice becomes more equal to the height of the wheel, or of the apertures of the directing blades. Again, the ratio of the velocity of the exterior circumference of the wheel to the speed due to the height of the fall, which corresponds with the maximum effect, increases with the opening of the sluice, and the more rapidly in proportion as the fall is greater. For wheels with an average head of from 10 to 14 feet, and a large supply of water, the velocity of the exterior surface of the turbine will be determined by the number of revolutions, which may vary between the limits $n = 5{\cdot}25\,\frac{V}{R}$ to $n = 7{\cdot}5\,\frac{V}{R}$; when the fall is between 18 and 26 feet, and the supply small, the formulæ become $n = 4{\cdot}50\,\frac{V}{R}$ to $n = 5{\cdot}50\,\frac{V}{R}$; and from the number thus ascertained the dimensions to be given to the various communications of movement may easily be calculated.

9. *Horizontal Wheel with Partitions.*

This was the form of turbine proposed by M. Burdin, and it also consisted of two parts, the one fixed and the other moveable; but, instead of placing them concentrically, one was put above the other. The most correct idea of this machine may be formed by representing to ourselves a circular basin, the bottom of which is pierced by a number of holes or orifices, widened at the top, so as not to diminish the fluid vein, and disposed in such a manner as to project the fluid at an angle which is most calculated to produce a good effect.

Immediately below this basin is the wheel: its upper portion forms a shallow circular trough; upon the bottom there is a series of small funnels close to one another, and having below tubes bent in such a manner as to have their upper portion vertical and the lower portion horizontal. The water descending from the orifices of the basin falls into the funnel at the bottom of the trough: it passes along the tubes, and acts upon them by its weight and by its centrifugal force.

The useful effect of these machines is 0·67 P H.

10. *Reaction Wheels.*

These wheels form parts of machines in which the water is contained within the mechanism. In leaving it, an effort is exercised, reacting upon those portions opposite to the discharge orifices, and producing a receding action able to be converted into a movement of rotation.

The useful effect of these wheels is so small (never exceeding, in fact, 0·65 P H, and very rarely attaining that limit), that it will not be worth while to dwell upon them longer than is necessary to describe one of the most successful instances of its adaptation by Manouri d'Ectot. The water descends a vertical shaft, and passes into a series of horizontal arms larger in the middle than at the apertures, and curved to the form of an $\backsim$. The water-communicating power is admitted below the wheel by a bend terminating at the centre.

Barker's Mill, and those constructed after the principles laid down by Euler, by Mathon de la Cour, and others, are but modifications of the above. Euler was very enthusiastic in his endeavours to introduce this machine; but in spite of his assertion "that it excelled all other methods of employing the force of water to produce motion," its practical value has been far below what we might have been led to expect.

Comparison of the different Descriptions of Water-wheels.

Wheels with straight floats working in a breast fitting closely, and with a sluice allowing the water to fall over its upper edge, produce a useful effect, after deducting

the friction of the bearings, of about 0·60 to 0·65 of the absolute power of the motive stream. They may, without any appreciable difference in their proportional results, move with very different velocities. They are the description best adapted to falls of from 4 feet to about 8 feet 6 inches in height.

As their radius ought to be at least equal to the height of the fall, if the latter exceed 8 feet 6 inches, they will become inconveniently heavy and cumbrous : they will also require a perfection of execution not easily attained in new countries or colonies. They have, moreover, the more serious inconvenience of not being able to work should any back-water exist in the tail bay.

The undershot wheels with curved floats, on the system of M. Poncelet, yield, as we have seen, 0·60 of the total motive power when the fall is about 5 feet and under, or 0·50 when that height is exceeded.

They can work with considerable velocity, which allows ot their making a greater number of revolutions than any other system of undershot wheels. Their width, and consequently that of the channel and the sluice, are, for an equal force, less than in the case of straight wheels. It follows that their construction is more economical, their weight less, and their establishment more easy in certain positions than is the case with any other undershot wheels. They can be flooded to the depth of their shrouds, without materially impairing their useful effect,—a great advantage in countries exposed to inundations.

An objection, or rather an inconvenience, attached to their use consists in the fact that if they be made to revolve at a velocity sensibly different from that of the maximum effect, the water will rebound into the interior of the wheel, and give rise to a corresponding loss of power.

They are particularly adapted to small falls of about 5 feet and under, possessing a great flow of water.

Bucket-wheels present the same advantage with wheels carrying straight floats working in a close breast, of yielding 0·70 of the motive power. They are particularly adapted to falls of 10 feet or upwards; and as they do not require to work in a close breast when their buckets are only half-filled, their construction is very economical.

As the water ought generally to pour upon them with a velocity of from 8 to 10 feet per second, and the falls are considerable, they are able to apply usefully great motive power without requiring an excessive width. In the case of great falls, also, they are able to work when the wheel is flooded to a height above the shrouds.

The breast-wheel is superior to the overshot when the supply of water is variable, and, from the fact that its diameter may be made to exceed the total fall, it is the most advantageous in cases where the first motion of the machinery is required to be considerable. The back-water, in times of flood, has less influence upon this class of bucket-wheel than any other : they can therefore work for a longer time, and to a much greater depth in back-water.

The majority of horizontal and reaction wheels have been found to be so practically useless, that they have been almost entirely abandoned, with the exception of M. Fourneyron's turbine. The Continental Engineers have a decided predilection for this class of machines upon the following grounds, stated by M. Morin, who has very closely examined their action.

They are applicable to any height of fall, from the least to the greatest hitherto employed. M. Fourneyron has himself executed one at Pont sur l'Ognon, working occasionally with only a head of 9 inches; he executed another at St. Blasier, in the Black Forest, for a fall of 354 feet.

From 0·70 to 0·75 of the net effective power may be obtained, and the turbines

may revolve even at velocities differing widely from that corresponding with the maximum of effect, without thereby giving rise to a notable loss of power.

In addition, they possess the advantages of occupying a very small space; they can be placed at almost any position where the power may require to be employed; and, as they may be made to revolve at much higher velocities than any other description of wheels, they obviate the necessity for multiplying gearing in the working machinery.

Works consulted. — Smeaton on the Power of Mills—Treatise on Mills, by John Banks—Practical Essay on Mill Work, by Buchanan—Fairbairn on Ventilated Water-Wheels—Fairbairn on Mills and Mill Work—Glynn's different Papers communicated to the Institution of Civil Engineers, and to Scientific Journals—Beardmore's Tables—Templeton's Millwright's Assistant, &c.—D'Aubuisson's Traité d'Hydraulique—Morin's Aide-Mémoire de Mécanique Practique—Claudel's Formules à l'Usage des Ingénieurs—Belidor and Navier's Architecture Hydraulique—Bossut's Recherches experimentales sur l'Eau et le Vent—Fabre, Essai sur la Construction des Roues hydrauliques—Poncelet's Mémoires sur les Roues hydrauliques à Aubes Courbes—Coriolis, Calcul de l'Effet des Machines—Egen, Untersuchungen über den Effekt einiger in Rheinland-Westphalen bestehenden Wasserwerke—Euler's Mémoires in the Transactions of the Berlin Academy—Bernouilli, Hydrodynamica—Transactions of the Society of Arts—Repertory of Arts, &c.—Transactions of the Franklin Institution, &c., &c.

The reader is also referred to the Elementary Treatise on Mills and Mill-work, by Mr. Glynn, forming part of Mr. Weale's Series of Elementary Works, for details with respect to the application of the power, the production of which alone has been considered above. An examination of the machinery required to effect the various operations of grinding flour, of sawing, spinning, weaving, gunpowder-making, &c., would have swelled this article to a very inconvenient extent.

WELLS.*—The term wells is usually restricted in its application to excavations by means of which water is obtained from, or admitted to, strata beneath the surface, able to admit of its passage in either an upward or a downward direction. In the former case, the water is obtained from shallow or from deep-seated sources by what are usually called wells, or from Artesian borings. In the latter case, the foul waters of certain industries, or the excess of supply of land springs, in some instances, are removed by what are called '*dead*' or '*absorbing*' wells. Strictly speaking, the excavations through which access is obtained to deep-seated mines, or to tunnels, and other underground operations, are wells; but it is more common to designate them by the term *shaft*, reserving that of wells to excavations formed expressly for the purpose of obtaining water, or for removing that which may be susceptible of becoming a nuisance.

The description of well to be adopted in any particular instance must depend not only upon the quantity required, but also, and to a much greater extent, upon the geological constitution of the district in which it is proposed to sink it, whether it be desired to form a supplying or an absorbing well. It becomes therefore necessary to state briefly the general conditions affecting the transmission of waters through underground strata.

* By G. R. Burnell, C.E.

Geological consideration affecting wells.

Most large hydrographical basins will be found to be bounded by the outcrop of some strongly-marked geological formation of an older date than the deposits constituting the principal portion of the district. In fact, there exists a remarkable concordance between the external configuration and the geological structure of a country. The bounding ridge circumscribing any particular basin usually assumes a concave form, and is filled in with strata more or less conformable to it, or to one another; and in the majority of cases, the lithological character of the more recent strata assumes a considerable degree of regularity in the alternations of the pervious and impervious beds filling in the basin. From the bounding ridge to the outfall there exists naturally a general inclination of the surface; and, if the water-course be ascended in the opposite direction to that of its flow, the successive strata will be found to outcrop, over areas differing in extent according to their thickness and the angle of their dip.

The rain-fall upon a basin of this description will be partially absorbed by the vegetation; partly it will be removed by evaporation; partly it will run off in the water-courses forming the superficial drainage of the districts; and the remainder will penetrate the permeable strata outcropping upon the surface. Of course there must be considerable difference in the quantities taken up by any, or either, of these agents; for the circumstances of the rain-fall, so far as regards its more or less equal distribution over the year,—the climate,—the more or less level character of the country,—will not only affect the volume of the water-courses, but also the evaporation, and the supply of deep-seated springs. It is, however, usually considered that about one-third of the total rain-fall runs away in the superficial water-courses; one-third is returned to the atmosphere by evaporation, or is absorbed by the vegetation; and the remaining third penetrates the ground to supply the deep-seated springs.

Should the surface of a large extent of country consist of permeable materials, such as gravel, sand, and some descriptions of loam, the water soaking into the earth will descend through it until it meets with an impermeable stratum. As no hydrostatic pressure exists upon it, the springs fed by the water so descending cannot rise above the ground, and they are found to follow the laws regulating the flow of surface waters, excepting in so much as the friction of the materials traversed may serve to retard their motion. The greater portion of the water will collect in the lowest part of the upholding stratum: if the sides be of equal height, and the dip of the latter regular, this will be found to be about in the middle of any depression; if, on the contrary, one side be steeper than the other, the lowest part will be found to be nearer the steeper side. No springs of importance will be found at the heads of valleys, but they are usually to be met with at the intersection of secondary valleys with the principal one of the formation. As also occurs with surface waters, the volume yielded by any underground spring is proportionate to the length of the valley supplying it, and the latter is always greatest when the secondary valleys of a hydrographical basin form an acute angle with the direction of the main valley. The conditions above stated actually exist in the district round London, where the Bagshot sand formations, and the gravels and loams formerly called diluvium, repose either upon the London clay or upon the chalk.

If, in the district supposed to be under examination, the strata consist of alternations of permeable and impermeable materials, and they successively crop out from under one another, forming a basin-shaped depression towards the centre,—the water falling upon the permeable strata will soak into them and fill the lower portion, if no outlet exist by which it may escape through the stratum upholding it in the other parts of its course, or by which it may rise to the surface with greater ease than it can continue its underground flow. Generally speaking, in a perfect basin, the

latter condition does not exist; the lower part of the water-bearing stratum passing beneath an impermeable one, then becomes, as it were, gorged with water, and any excess arising from the upper parts is thrown off at the surface by the springs, which serve as the overflow for such strata. Should any artificial opening now be made through the upper impermeable stratum, a species of inverted syphon will be formed, in which the vertical branch, being at a level usually below that of the longer inclined leg, will afford an outlet for the pent-up waters. The waters in the subcretaceous, in some of the oolitic, and the old and new red sandstones, exist under these conditions in England and in France: the tertiary strata in the latter country exhibit these phenomena to a greater extent than in our own country, although they may be observed both in the London and Hampshire basins.

When, therefore, it is desired to obtain water from a formation known to be entirely superficial, the most favourable position for the search will be in the lower parts of the plain succeeding the intersection of the primary and secondary valleys. Such formations are rarely of great depth; and as the hydrostatic pressure upon the underground stream is very small, if large supplies be required, it will be necessary to form a species of reservoir to store the water flowing during the intervals of its withdrawal. For small depths it is more economical to sink a well than it is to bore; and as the size of the well usually enables it to perform the function of a reservoir, we find that water is almost always obtained from such superficial deposits by wells.

The supply derivable from these sources is rarely of a sufficiently copious nature to satisfy the wants of a closely agglomerated population, and should the latter exist in the localities where it is required to obtain water, it will almost always be found that the percolation of the drainage and sewage waters will affect the qualities of that which would, in such positions, find its way into the wells. Under these circumstances it may frequently be found advisable to obtain a supply from the water-bearing strata underlying the impervious superficial deposits, or even when more than one water-bearing stratum exists, to resort to a lower one, rather than to a source nearer the surface possessing any particular chemical nature. The water in such underground sheets, being subject to a pressure equal to that of a column of water whose height corresponds with the difference of level between the outcrop and the point where the opening is formed through the retentive upper strata, minus of course the loss of head arising from the friction in its traject, is able to flow into the aperture with a rapidity equal to that at which it is withdrawn. A much smaller excavation will then suffice to insure a constant supply, because in fact the lower water-bearing stratum constitutes a natural reservoir. It is in such cases that it is found advisable to resort to boring, or the formation of what really is a descending tube, whether lined, or not, with pipes, of a diameter sufficient to discharge the quantity of water required. From the circumstance that wells of this description were first employed in modern Europe in the province of Artois, they have acquired the name of Artesian Wells.

Common wells.

In the formation of common wells, the subjects to be considered are—firstly, the diameter and the depth to be given; secondly, the manner in which the sides are to be consolidated; and thirdly, the mode to be employed in raising the water.

Dimensions.

1. From what has been already stated, it must be evident that the two first considerations, with respect to the diameter and the depth of the well, are not susceptible of any absolute *à priori* mode of determination. Local circumstances will cause them to vary in almost every case, not only because the water-bearing stratum itself is of a different nature, but also because the rate of consumption from the well differs in each of them. A careful examination of the wells already executed, or a comprehensive geological survey of the surrounding district, are necessary before commencing such works. But it must always be borne in mind, that invaluable as

are the indications of theoretical geology in this as in all other branches of engineering, the inductions derived from it require to be verified by actual experiment. In the case of underground waters, for instance, if any interruption of the regularity of the substratum occur, either from a fissure or from an irregularity of form in the outline of the basin, such as often exists without any external indication, we are exposed to find that the conditions of the lower part of the stratum from which we expected to derive a supply of water may be very different from those we might have been entitled, *à priori*, to expect. The first attempts to derive water from any formation must therefore be always exposed to a certain amount of risk. The different results obtained in the Paris and Brighton Artesian Wells from those obtained at Highgate, Harwich, Calais, &c., may be cited as illustrations of the uncertainty attending this class of operations.

Should any wells exist, the dimensions to be given to a new one to be formed in any locality will be ascertained by observing the height of the water-line in them at the different seasons of the year, and the rate of supply must be ascertained by observing the extent and manner in, and the level to, which the water may be lowered by pumping. In some cases also it may be necessary to ascertain the area of what may be called the contributing ground, in order to form a correct opinion as to the capabilities of the source of supply to meet any other demands which may arise. In no country in Europe does any legislation exist by which a right of property can arise with respect to the flow of underground waters. It is therefore possible that the supply may be cut off from a well entirely, or at least considerably diminished, by the execution of similar works in the immediate vicinity. Before founding any establishment depending upon its supply of water from such underground streams, it therefore becomes essentially necessary to ascertain all the circumstances affecting the latter.

When the extent to which it is possible to lower the water-line shall have been ascertained, the depth to be given to the well, and the position to be ascribed to the bottom of the rising main of the pump, will be fixed so that the latter shall always be below the surface of the water in the well, and that a sufficient quantity of water may exist under it to maintain the efficient action of the pumps. A depth of from 4 to 6 feet below the line of permanent depression will be sufficient for all ordinary purposes; a diameter of about 4 feet in the clear of the finished work will also be all that is required for domestic or small trade uses.

2. The manner in which the sides of a well are to be lined, or as it is commonly called *steined*, will depend equally on the nature of the strata to be traversed. The objects proposed to be effected by such works are to prevent the incoherent materials of the sides from falling into the well, and to exclude occasionally such land waters as may be likely to contaminate those furnished by the lower stratum. In stiff clay, gravel, or chalk of great consistency, a thickness of half a brick will usually suffice for the *steining*, and in many cases it may be even executed without mortar. The thickness will naturally be increased if the strata are more exposed to slip, or if land springs are to be excluded: in the latter case it becomes necessary that the materials employed should be of a nature to resist permeation through their substance. Brickwork in cement of considerable thickness, and cast or wrought iron curbs, are frequently employed in such cases.

The steining, of whatever materials it be constructed, is put together or built upon a bottom curb made with a cutting edge, and the ground is excavated from beneath this curb equally all round. The curb then descends by its own weight, and is retained in its vertical position by means of guides; the brickwork is added from the top, and this operation is continued until the curb will sink no longer, owing to the

swelling of the ground : a new curb and new excavation are then begun, smaller than the last. In modern practice, when the ground is of a nature to maintain the already executed steining by its friction against the sides, or where there exist means of suspending the steining, it is usual to add the brickwork under the portions previously executed. It is impossible, however, to lay down any absolute rule for the execution of such works ; the judgment of the engineer will suggest the modifications required to meet any local peculiarity or difficulty, either arising from the configuration of a district, or from considerations of economy in the execution.

3. The means to be employed in raising the water will depend upon the depth of the well, and the extent of the demand, as also to a great extent upon the relative positions of the place where the water is to be used, and of the well. For ordinary purposes, buckets or hand-pumps will suffice. When large quantities are required, some of the modifications of water-raising machinery, already noticed in the article upon 'Water Meadows,' must be resorted to.

Should further information on this subject be required, the reader is referred to Weale's 'Elementary Treatise on Well-Digging and Boring.'

Artesian wells.

In the construction of Artesian wells, the preliminary investigations require to be of a much more elaborate nature than those necessary before commencing an ordinary well, not only because the source of supply is found to exist at a greater distance, but also because the uncertain element of the underground disturbances assumes a much greater importance ; and this is more particularly true when an attempt is made for the first time to reach a new source of supply. It is necessary to ascertain the relative heights of the outcrop of the water-bearing stratum, and its nearest overflow, with respect to the position of the proposed well, in order to arrive at some conclusion as to the probable height of ascension of the water when it shall have been reached. It is also necesary to ascertain the surface of the outcrop and the thickness of the water-bearing stratum in its passage beneath the retentive upper stratum, for upon these conditions will depend the capacity of the former to yield a constant supply. The existence of any fault or dislocation of the strata must also be carefully sought for, because, should such exist, either the water contained in the permeable stratum may find a more ready outlet to a lower level, or its circulation may be cut off from the particular part of the basin where it is proposed to place the well.

In the tertiary strata, the conditions requisite to insure the success of an Artesian well are more likely to be met with than in the secondary formations. Generally speaking, the tertiary strata are composed towards their base of sandy permeable materials, covered by impermeable clays or compact limestones, that is to say, of precisely the materials required to maintain a continuous flow of water, in case the upper member of the series be traversed. They are also less frequently interrupted by disturbances of the strata able to modify the subterranean hydrography, for there do not appear to have occurred any great geological cataclasms subsequently to their deposition. Their circumscribed areas also render it more easy to calculate the influence of the different phenomena affecting the flow of water within them.

In nearly all formations, however, the general law prevails by which the base is constituted of a series of sandy permeable deposits, marking the epoch of change from one geological condition of the globe to that immediately succeeding it ; and these permeable deposits are covered by others of a totally different character. It almost always happens also, that the outcrop of the permeable strata occurs at an elevation superior to that of the position in which it is usually required to bore for water. In many cases also, compact limestones acquire the faculty of transmitting a subterranean current, either from their being traversed by great clefts, or from their being fissured in every direction. The chalk formation, perhaps, offers the most striking

illustration of this condition, and it is principally from such fissures that the wells in the Artois derive their supply; but it is frequently to be met with in the lower secondary formations, particularly in the carboniferous series.

Of the Artesian wells already executed, the most numerous are those to be found in the basins of London, of Paris, of Modena, in the secondary formations of Tours and Rouen, and the whole of the Artois, and of Upper Normandy, in the greensand below the chalk of Nancy, in the marls of the new red sandstones, and of Derbyshire and Lancashire in the same series of deposits.

If we cannot predicate with certainty in what formations water will be found by means of an Artesian well, this much is known, that the primary and transition, or metamorphic, rocks are never likely to exist under the conditions requisite to insure its success. In them the subterranean currents can only permeate along the lines of cracks or fissures whose direction is sufficiently capricious to defy calculations. Again, in sedimentary deposits much affected by geological disturbances, or in elevated districts which are not surrounded by the outcrops of a permeable stratum at a higher level, and passing beneath those to be operated upon, there can hardly be said to exist any reasonable prospect of success. It is only in regularly stratified deposits which have not been subsequently disturbed there can be said to exist any certainty of obtaining a supply by the formation of an Artesian well. As will be shewn hereafter, the same theoretical reasoning upon the geology of a particular district applies equally to Absorbing Wells.

Where many Artesian wells are sunk in the same formation, there results a diminution in the rate of supply, which may seriously affect their value; so much so, in fact, as to render it doubtful whether some legislative interference be not required to maintain the rights of the parties first applying the water obtained, at what must always be a considerable risk and a great outlay. The diminution of the supply from the original Artesian wells round London, from those of Tours, and from those near Modena, owing to the unlimited formation of other wells, is a matter of public notoriety.

In sinking an Artesian well, the first operation consists in forming an ordinary well to a depth to be regulated by the yield of the water-bearing stratum and the probable demand; at the bottom a guide-pipe, able to admit the largest tools to be used in the boring, is to be fixed carefully in a vertical position, and above this, at the highest point to which the water can rise, is to be placed the stage upon which the rods or other implements are to be put together. The sheer legs or frame supporting the boring tools, are placed immediately over the guide-pipe, care being taken that there be sufficient height to allow of the easy withdrawal of the rods composing the tools,—these are usually made from 10 to 20 feet in length. Beyond the sheer legs are placed the crab or hoisting machinery, and the appliances by means of which the percussive action is communicated to the different tools. The latter necessarily differ according to the nature of the strata to be traversed, and it is found that every contractor modifies them according to his own ideas, and according to the description of power he may employ. However these details may be modified, the operations required to be performed at the upper level will still remain the same; and they will consist in lowering the rods, turning the augers in soft strata, impressing a percussive motion in harder ones, and withdrawing the loaded tools or buckets. To effect these objects satisfactorily, will require great skill and attention, so as at the same time to secure the greatest economy and despatch. Indeed there are few branches of engineering practice which require so much empirical knowledge as the boring of Artesian wells, or in which so much depends upon the skill of the contractor. By far the best work existing upon the subject was written by one of those gentlemen, M. Degoussée,

and it would be impossible to refer the reader to any work more likely to convey useful and practical information upon the subject than his 'Traité de l'Art des Sondages.' M. Kind, a German Engineer of great ability, has, it may be added, introduced some modifications of the boring tools by means of which he is able to execute with great rapidity, and at a small cost, deep borings of large diameter.

In consequence of the improvements introduced of late years into the execution of Artesian wells, they can now be carried to depths varying from 1200 to 1600 feet with tolerable facility. The diameter of the bore, and the greater or lesser degree of hardness of the rock, will, however, affect the rate of its progress, and consequently its price. In proportion, also, as we descend, the difficulties, and the time attending the separate operations, and the increasing danger of a rupture of the tools, tend to increase the cost; and, moreover, the time employed in lowering the tubes, and the precautions to be observed in traversing any running sands, augment as the depth increases.

A very important observation is to be made with respect to Artesian wells, namely, that the temperature of the waters they are likely to yield will be found to be regulated by the depth of the water-bearing stratum. The law of the increase of temperature in descending below the surface varies in almost every district. Thus, in Scotland, the mean rate of increase has been ascertained in the carboniferous series to be about 1° Fahrenheit for every 48 feet in depth, after passing the point of uniform temperature. At Rouen, in the chalk formation, it was found in one instance to be 1·8 for every 67 feet 4 inches, and 1·8 for every 100 feet in another; whilst at Paris it was carefully ascertained to be about 1·8 for every 106 feet of vertical descent. In the well at the latter town the temperature of the water was found to be very nearly that which would be indicated by a theoretical calculation; for the latter would have led to the conclusion that it should rise to the surface with a temperature of about 81° 96′; and, in fact, it rises at the temperature of 81° 81′ from a depth of not less than 1802 feet English.

The practical details connected with the execution of Artesian wells are treated of in the 'Elementary Treatise on Well-Digging and Boring' already alluded to.

Absorbing wells. In many positions in our own country the practice of sinking dead wells for the purpose of carrying off the waste waters of certain factories exists very commonly. They are, however, limited to excavations in the superficial strata, and are really nothing but shallow wells acting in an opposite direction to ordinary ones. This branch of engineering has escaped the notice of the legislature, like so many others connected with wells, and there does not appear to exist any law in England to prevent the evacuation of the foulest waters by means of dead wells, even when others for the supply of water for household purposes may exist in their immediate vicinity, and be fed by the same stratum. It is more than probable that the contamination of the shallow wells observed in most large towns, on the Continent equally as in England, may be attributed to some such action, which must operate with a rapidity and an intensity proportionate to the quantities of water in the well and in the basin receiving them.

It appears, however, that the injurious effect of dead wells does not spread to any great distance, for a work of that description executed at the Hospital at Bicêtre, by means of which the foul waters of an establishment able to accommodate 4000 men were made to descend to a subterranean stream, did not affect the ordinary wells supplied by that stream, unless it were during very heavy storms, at a distance of from 500 to 700 yards. In the case of absorbing wells by borings, the remarkable ascensional power of the water also seems to be a guarantee against its being contaminated by any foul waters let down from above. The danger would also, in all

probability, be less if they were made to descend to a formation so absorbent and at the same time so shattered as the chalk, particularly in its upper members. In some localities wells are almost unknown, so that there may be occasions in which it would be advisable to adopt this means of removing foul waters, even should the use of dead wells be attended with serious injury to the public health in other positions.

It has been ascertained by direct experiment that any description of well can absorb as much water as it is able to produce. Thus, if a boring should yield 50 gallons per minute, and its ascensional power cease at a yard from the ground, if the tube be prolonged for a second yard, 50 gallons per minute may be poured into the tube without the waters flowing over the orifice.

If a boring yield 50 gallons per minute, and it be desired to make it absorb 500 gallons in the same time, a pump able to remove the latter quantity is to be set in action, and notice to be taken of the extent to which it can lower the water-line. Should it be about 30 feet, for instance, it will be sufficient to lengthen the tube of the bore to a height of 30 feet above the natural water-line, and the quantity of 500 gallons may be poured in. Of course, if the water do not rise in the bore to the surface, the absorption will be more rapid.

Absorbing wells may be either formed in the same manner as ordinary shallow wells or by Artesian borings. In either case it is advisable to exclude surface or land waters from them, and they should therefore be close-steined or piped. Precautions require to be taken to clarify the waters as completely as possible by deposition or filtration ; in fact, the solid matters in suspension must be removed, or the absorbing faces will become rapidly choked. It is easy to effect this object by forming a reservoir to receive the waters to be evacuated, and by carrying the end of the pipe some height above the bottom ; the deposit in the reservoir must be removed before it can reach the level of the entrance of the descending pipe, and it would certainly be preferable were the latter covered by a grating, or cap, able to retain the grosser particles. Should the absorbing surfaces become choked, it is easy to renew them by excavation or by the use of a boring auger with a ball-clack. But however well the operation of cleansing the absorbing faces may be performed, the useful action is never equal to that which originally took place ; and it is therefore impossible to dwell too forcibly on the necessity for observing the greatest precautions in preventing the descent of any solid matters.

One of the most useful applications of absorbing wells would be for the purpose of draining clay lands, when the clay is of moderate thickness, and it lies immediately upon a permeable substratum. The boulder clay of Norfolk and Suffolk, reposing upon the chalk, may be cited as an instance of the description of formation adapted to the application of this method. In many cases it will be found more economical to sink an absorbing well, or even to make a succession of small borings, than to execute a great and expensive outfall-drain.

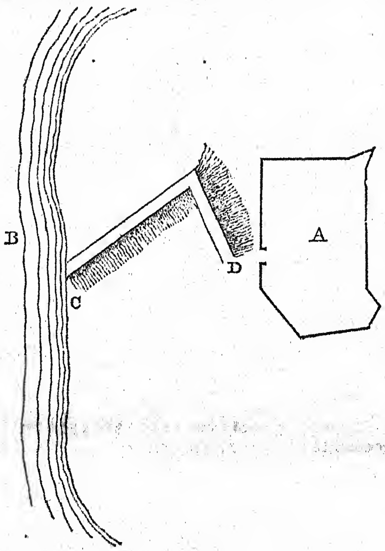
Generally, unless the spring supplying a well be of a nature to maintain a constant flow and interchange of its water, it must always be borne in mind that the latter is to a great extent stagnant. Its qualities must, therefore, participate of those of all stagnant waters, and as such be more or less objectionable on account of its want of aeration, and the partial decomposition which must affect them. An equally important observation is, that well-water is exposed to take up the soluble salts contained in the materials it traverses. It is indispensable, then, that only such materials be employed as are not likely to furnish any injurious salts ; that, in fact, as was observed in the article upon the 'Water Supply,' silicious stones, or hard-burnt bricks, or iron tubes,

should be used in preference to such stones as would be likely to give forth the sulphates or carbonates of lime.

The reader is referred, for further information upon the whole subject of wells, to Mr. J. Prestwich on the Water-bearing Strata of London, &c.,—Mr. Clutterbuck and Mr. Dickinson's Papers on the Water Supply of London,—Mr. Stephenson's and Mr. Homersham's Reports on the Watford Spring Water Company, &c.,—to the different Reports on the Metropolitan Water Supply and the Health of Towns,—Amedée Burat's Geologie appliquée,—Degoussée, Guide du Sondeur,—the detached Papers by M. D'Archiac and the Abbé Paramelle, MM. Hericaut de Thury, Garnier, and Emery, —Les Annales des Mines,—Nieues Jahrbuch für Mineralogie und Geognosie. A long Report upon Absorbing Wells, by MM. Girard and Parent Duchatel, will be found in the Annales des Ponts et Chaussées for 1835.

Z.

ZIG-ZAG.—An insignificant term in itself, but important in siege operations; *zig-zag* being the principle on which the attack of places is based; and this mode of approach had long been in use in a rude way, until perfected by Vauban.



Zig-zag is not only the proper course by which to advance in sieges, but it is the method of connecting the parallels and places of arms, and finally arriving at the close of the attack or breaching batteries, and the work is usually effected by Sap.

The object of making zig-zag a special subject for the 'Aide-Mémoire' is to suggest the application of this mode of advancing to irregular attacks of posts, barriers, and stockades, and thus saving many valuable lives, with the loss of a very little time; and by taking advantage of some hollow or natural cover, or of some adjacent building, a few Sappers could run a zig-zag up to the work in two or three hours, under the protection of musketry-fire, and finally place a quantity of gunpowder for forcing the gate or barrier, or the destruction of a stockade or other slight defence, such as savages or insurgent inhabitants throw up on the spur of the moment.

The following example will shew how this idea may be applied:

Supposing it desirable to force a work A, an approach may be commenced from the hollow B, and a zig-zag carried up to the entrance D, forming a short line of Sap, C D, where a quantity of powder could be fixed at the point D, which would on the explosion enable the attacking party to rush from the hollow, and, taking advantage of the confusion, carry the work.—G. G. L.

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